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Prepared for

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Toxic Substances

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Proceedings of the National Workshop on Substitutes for Asbestos

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The Environmental Protection Agency

The Consumer Product Safety Commission

The Interagency Regulatory Liaison Group

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The purpose of the National Workshop on Substitutes for Asbestos was to obtain more information on the technical and economic feasibility and possible health problems of substitutes for asbestos, for use in considering regulation of asbestos. Some of the topics discussed include: Non-asbestos friction materials; Discussion on friction products; Gaskets and packings; Asbestos in plastics; Discussion on plastics and flooring; Single-ply roofing as a substitute for asbestos roofing felt; Mill applied coatings for underground pipelines; Discussion on pipeline wrap; Discussion on textiles; Asbestos substitutes in roof coatings, sealants, and cements; Substitutes for asbestos-cement sheet; Inhalation, deposition, and clearance of particles; Man-man vitreous fibers and health; Discussion on the translocation and fate of sized man-made mineral fibers; Exposures to mineral wool; Toxicology, aspects, ...
KEYWORDS: *Asbestos, *Meetings, *Synthetic fibers, *Glass fibers, *Carbon fibers, *Ceramic fibers, *Fibers, *Industrial hygiene, *Occupational safety and health.

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November 1980

PROCEEDINGS OF THE NATIONAL WORKSHOP ON SUBSTITUTES FOR ASBESTOS

Arlington, VA, July 14-16, 1980

Sponsored by:

United States Environmental Protection Agency
United States Consumer Product Safety Commission
Interagency Regulatory Liaison Group

Arlene Levin, Co-editor

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Office of Pesticides and Toxic Substances
U.S. Environmental Protection Agency

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Pesticides and Toxic Substances
Washington, D.C. 20460

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Convention of the National Workshop on Substitutes for Asbestos and publication of this document do not signify that the contents necessarily reflect the joint or separate views and policies of each sponsoring Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

The purpose of the National Workshop on Substitutes for Asbestos was to obtain more information on the technical and economic feasibility and possible health problems of substitutes for asbestos, for use in considering regulation of asbestos. The Workshop was co-sponsored by the Environmental Protection Agency (EPA), the Consumer Product Safety Commission (CPSC), and the Interagency Regulatory Liaison Group. It was held at the Sheraton National Hotel in Arlington, Virginia, July 14 to 16, 1980. It was attended by over 600 people from industry, government, public interest groups, labor, and other interested parties.

Most of the technical/economic portion of the workshop consisted of talks on substitutes for asbestos product categories, followed by question and answer periods. Eight roundtable discussion sessions were held concurrently for each category of substitutes for asbestos. An evening panel discussion was held in which representatives from industry, government, labor, and environmental groups discussed substitutes for asbestos. On the second day of the workshop, a session was held in which manufacturers and other experts on asbestos supplied information about substitute materials and products.

The second portion of the workshop focused on health effects of both fibrous and nonfibrous types of substitutes. An overview on routes of exposure was presented, followed by papers on epidemiological and experimental studies of various substances that can be used as substitutes for asbestos. Discussion sessions followed the presentations. An evening session was held to discuss the health aspects of exposure to talc.

Chairmen

Richard J. Guimond and James N. Rowe, Ph.D.
Office of Pesticides and Toxic Substances
U.S. Environmental Protection Agency

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The editing work on the Proceedings, performed by the EPA and CPSC staff and their contractors, GCA Corporation and Merenda Associates was also very much appreciated.

INTRODUCTORY REMARKS

by

Chairman Richard J. Guimond
U.S. Environmental Protection Agency
Washington, D.C.

Welcome to the first National Workshop on Substitutes for Asbestos. I will be chairing the technical and economic sessions of this workshop.

We hope you find the meeting informative. I have been looking through the presentations and I have found much that I was not aware of before and much that has expanded our horizons.

There are going to be eight Roundtable discussions. There is a list of questions, issues, and topics that we would like to take up in those Roundtables. The first page of the handout for the Roundtable discussion is a general set of questions that apply to all Roundtable discussions, but the remaining pages focus on the individual sessions. There is a session for asbestos friction products, reinforced plastics, flooring, gaskets and packings, paper and roofing products, textiles, asbestos cement sheet, and asbestos cement pipe. People are free to move around the various sessions, in case you want to learn about more than one topic or participate in more than one session.

Because of the large number of participants attending the meeting, I am going to ask that all remarks or questions be held to 3 minutes, so that everyone has an opportunity to ask a question or to make their comment.

REGULATORY STATUS

by

Dr. Peter Preuss
U.S. Consumer Product Safety Commission
Washington, D.C.

and

Dr. Warren Muir
U.S. Environmental Protection Agency
Washington, D.C.

DR. PETER PREUSS

We are here at this workshop to try to learn from you about an issue that is of a great deal of concern in many places. Some of you may not be entirely familiar with the Consumer Product Safety Commission (CPSC) and what we do and how we function. The Consumer Product Safety Commission is an independent agency headed by five commissioners and a chairman appointed by the President. Basically, we administer two statutes that allow us to deal with and regulate asbestos, other hazardous materials, and health and safety issues related to consumer products.

Under the Consumer Product Safety Act, the Commission has the general responsibility to protect the public from unreasonable risks of injury, illness, or death associated with consumer products.

The second Act, the Federal Hazardous Substances Act, allows us to regulate hazards presented by the presence or use of toxic and other hazardous substances.

In the past, the agency has used both of these Acts in controlling substances they felt posed a hazard. Regardless of which statute we have used in the past or which we might use in the future, one of the keys to effective regulation is having not only good communication from all involved parties, but also having regulations that are based on good and appropriate information. This has been one of the issues that I have been speaking about ever since I came to the Commission about a year ago because it has troubled me that there has not been a sufficient flow of information. And whether it was at the meeting of the Asbestos Information Association or a variety of other forums where I have been privileged to represent the Commission, I have tried to make this point: that our regulations and our efforts are, indeed, limited by the quantity and quality of the information that we have available to us at the time that we make our decisions.

Now, on this issue specifically, that is the use of asbestos and asbestos substitutes, we have made a number of attempts over the past 8 or 10 months to try to acquire some of the information that we felt was important and necessary. In October of last year, the Commission, together with EPA, published an Advanced Notice of Proposed Rulemaking (ANPRM) where we, in general, outlined our thinking and our approaches to the question. CPSC, in particular, tried to get some idea of the scope of the potential problem posed by consumer products containing asbestos. A number of very specific questions were asked at that time.

And since then, we have followed through in the direction that ANPRM had indicated. Very recently, the Commission has voted to approve a General Order that requires the submission of information about the use of asbestos in a variety of consumer products. The point is to obtain some very specific information for a number of defined and specified consumer products. We hope that these kinds of efforts will provide us with the information that is important and necessary to make our decisions.

In addition, we have just completed setting up a test facility in Chicago to look at asbestos and other fibers as they may be emitted from consumer products. That laboratory is now beginning to look at many materials and products. This kind of effort will become more important and the information we gather will become more important as we move from asbestos to some of the substitute materials.

I think one of the points of this workshop is that if we have learned anything from our past efforts, it really is very important to try to accumulate the information and assess and evaluate the information before we go too far down any one road. We cannot wait until materials are in widespread use, until everybody is exposed, or until they are present in all parts of the environment before we begin to look at deleterious health effects.

So we are looking forward, during these 3 days, as a regulatory agency, to obtaining some of the information dealing with the identity, the uses, and the possible adverse health effects from consumer exposure to this potentially very large group of materials that we are, for convenience, calling "asbestos substitutes."

I want to point out that this workshop, although the headings indicate "EPA/CPSC," is more than just an effort of these two agencies. It is, indeed, an effort that is being coordinated by all of the agencies belonging to the IRLG, the Interagency Regulatory Liaison Group, which is composed of five agencies. In addition to the EPA and CPSC, there is the Food and Drug Administration, the Occupational Safety and Health Association, and the Food Safety and Quality Service of the Department of Agriculture. I mention this because these IRLG agencies have been working very hard over the past year on this topic of asbestos and asbestos substitutes to try to make sure that we are sharing information; that we are not stepping on each other's toes', that we are not duplicating efforts; that we make sure what we are doing is as coherent and as reasonable as we can possibly make it so that this workshop and the information that comes from it will clearly be shared with all of those agencies.

Again, these agencies, the IRLG agencies, have been looking for ways to foster communication and to try to be a little bit more innovative than in the past. Hopefully, this workshop will serve as a model for that effort, and so, after the 3 days are over, we will all agree that we have benefited from this exercise. We will have benefited particularly by learning a great deal from you; by learning a little better what our needs are; and jointly, by understanding how we can communicate a little bit better with each other.

The workshop is structured in a way to allow maximum participation by all of the people who are attending. And to get those of you who, clearly, know much more about many of these specific areas to participate with us and to try to share knowledge. The sessions will cover a variety of topics, everything from physical uses to health effects. I think you all have an obligation to, in fact, participate with us in these efforts so that we can make this workshop a success. And, again, I think that the more informed we are, as regulatory agencies, as we proceed in our regulatory investigations, the better our chances are of obtaining the best results.

DR. WARREN MUIR

We in the Office of Pesticides and Toxic Substances are currently conducting a rulemaking investigation on the commercial and industrial uses of asbestos. We are holding this conference as part of our investigation in an effort to expand our knowledge regarding the substitutes of asbestos. We want to learn as much as possible about asbestos substitutes in various product categories. We are eager to learn about their performance, their cost, and any health and environmental risks that they may pose. This rulemaking proceeding is being conducted under the Toxic Substances Control Act, more often referred to as TSCA. The Act required that EPA eliminate unreasonable risks of human and environmental injury posed by chemical substances.

Several factors are involved in evaluating whether or not asbestos, or any chemical substance or mixture, presents an unreasonable risk. To promulgate a rule to control risks from exposure to asbestos, the EPA plans to consider the following three things and, indeed, such factors would weigh into any control regulation under the Toxic Substances Control Act.

The first of these is the hazard of asbestos on health and the magnitude of exposure to humans. Secondly, the benefits of asbestos from its various uses and the availability of substitutes. And thirdly, the reasonableness of the ascertainable economic and regulatory impact of any rulemaking that we would undertake. These three factors would enter into, generally, any regulatory action that we would take.

EPA's preliminary health assessment, which we have been undertaking, indicates that asbestos poses a substantial risk to human health. The various toxicological characteristics of asbestos have been well known for many years and our assessment has, in essence, confirmed those relatively well known characteristics.

This conclusion has prompted our initiation of the rulemaking proceeding. In deciding on the specifics of such a rule, we felt it appropriate to investigate the substitutes of asbestos; and, hence, we are interested in participating with the Consumer Product Safety Commission in undertaking this workshop. We wanted to make sure that we had made a careful examination of the availability of reasonable substitutes for the various uses of asbestos and, therefore, we are investigating both those substitutes already available commercially and those anticipated to be available in the near future.

EPA wants to know about the good and bad characteristics of the substitutes so that our decisions will reflect the best information available. This workshop is one of our efforts aimed at gathering and evaluating such information. As Dr. Preuss has pointed out, our ability to undertake these actions, in any reasonable fashion, is really predicated upon a good information phase.

Other information collection actions include contractor studies and comments on an Advanced Notice of Proposed Rulemaking that we had in the Federal Register. Under our current schedule, we expect to complete our deliberations, to the extent that the agency could propose a suitable role regarding commercial and industrial uses of asbestos by this winter. This will be a proposed rule.

We expect that this workshop will provide us with valuable data and information, as well as perceptions of the industry, environmentalists, academia, and the public. The more informed we are, as we proceed in our regulatory investigation, the better our chances of obtaining an optimal result, namely, the elimination of unreasonable risks from exposure to asbestos while minimizing the adverse impacts of such a regulation.

We have structured this workshop to provide us with a broad array of viewpoints regarding the substitutes of asbestos. We have representatives from companies that use asbestos to achieve various product characteristics; those that are suppliers of asbestos; manufacturers of substitutes; research scientists; concerned private citizens, and others. We also have representatives from industry and elsewhere on the possible asbestos substitutes currently available or projected.

I would like to focus on some of the specifics about the workshop. The kind of information we are looking for covers substitutes for the many uses that have been found for asbestos. We want to know about their technical performance, their economics, and their effects on human health through the environment.

We have divided these uses into eight product specific categories, which are friction products, gaskets and packings, plastics and floorings, paper products, textiles, sealants, asbestos cement sheet, and asbestos cement pipe. This will enable all of us to focus on specific areas of interest and concern, and will help us obtain information and advice from the most qualified people in each of the respective fields. The technical performance of asbestos and the economic aspects of developing, marketing, and using asbestos substitutes will be discussed within each of the category review sessions.

In evaluating substitutes our initial step is to determine the range of uses within each product category. From this we can find out where substitutes are available for product categories or subsets of categories and how they perform technically. We want to look at both the general fiber substitutes for asbestos and at substitutes for specific asbestos products. We want to know about the technical limitations of the substitutes present; for what applications are there no feasible substitutes; and how much has been invested in research and development to find such substitutes.

We are also concerned about the economic and practical impacts of conversion to asbestos substitutes. We are aware that there are many situations where economics may prevent the use of a substitute. Where has this occurred, and how might the situation be improved? What are the estimated conversion costs in the various product industries? Would industry requirements be altered significantly, and are there performance standards and regulatory guidelines that might encourage or inhibit the production or introduction of any such substitutes? These are a few of the topics for the Round Table sessions.

And, finally, we will be addressing the health aspects of various fibrous and nonfibrous substitutes, both synthetic and natural. We will review the routes of exposure and the results of exposure to various substances, many as reported in studies and surveys of exposed workers in several industries.

We have set aside some time for open discussion on the evaluation of criteria for health studies and on the scientific evaluation of substitutes. We are here to learn; we have come with open eyes and open ears. We hope that you will do the same. We want to know all sides of the issue, the essential uses for asbestos, those applications for which there are no feasible substitutes yet available, and those for which substitutes exist and may even be superior.

The workshop is not the end of our search for information. We hope that it will stimulate your thoughts and generate new ideas. So, if you have any additional data, information or comments, or wish to elaborate on any of the discussion that has occurred during the workshop, we would encourage you to make that available to us.

NON-ASBESTOS FRICTION MATERIALS

by

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and

Mr. Charles M. Brunhofer and Mr. F. William Aldrich*
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ABSTRACT

Friction materials for automotive brakes are complex composites containing three general types of ingredient materials: reinforcing fibers; modifiers that adjust or maintain friction level, wear rate, and noise properties; and organic resin binders. Historically, the foundation or major constitutent of automotive friction materials has been asbestos fiber, so chosen because of thermal stability, friction level, reinforcing properties, availability, and relatively low cost.

Numerous substitutes for asbestos in conventional organic materials have been evaluated, including both naturally occurring and synthetic materials. Direct substitution of these alternative materials in conventional formulations has resulted in poor friction levels, friction instability, roughness, structural failure, increased noise, mating surface deterioration and/or front-to-rear vehicle brake imbalance. Complete reformulation, not simple substitution, is necessary to meet the numerous, complex performance requirements of consumers, manufacturers, and government standards, such as FMVSS 105-75 and FMVSS 121.

In the 1960's, a new class of friction materials, called semimetallics, was developed to meet severe braking requirements, primarily in heavy-duty disc brake and extreme duty truck block applications. Semimetallics operate satisfactorily against the ventilated cast-iron rotors in the smaller brakes of downsized cars, as well as against the solid rotors found in the lighter brakes of new front wheel drive vehicles. Semimetallics rely on steel fiber and powder metallurgy techniques for reinforcement, and do not require asbestos. The improved performance of semimetallics compensates for their higher costs due to more expensive ingredients, higher specific gravity, and more costly processing requirements. Overall development took more than 10 years from introduction to significant customer acceptance.

---

*Presented by Mr. Charles M. Brunhofer

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The characteristics of semimetallics make them extremely difficult and costly to process as a drum lining segment. Consequently, an additional new class of friction materials is under development, specifically for drum lining applications. Additional development effort is necessary, not only to confirm the performance characteristics of these new substitute fiber formulations, but also to develop new processing techniques. These new-type friction materials will be more costly, however, due to the ingredients and new processing techniques.

INTRODUCTION

Automotive brakes can be viewed, quite simply, as energy transformers. During a brake application, the friction material (stator) makes contact with the rotating drum or disc (rotor), creating a friction force resisting the relative motion between the two bodies. The energy of motion is transformed into heat energy, which is dissipated, primarily through the rotating member.

As one might expect, the friction material must operate in a rather hostile environment. Lining soak temperatures in excess of 400°C (750°F) are not unusual, and temperatures at the contact interface can exceed 850°C (1560°F). The nature of the on-the-road operating environment (dust, mud, salt, water, etc.) complicates the problem. The friction material must possess an optimized balance of characteristics, and maintain those characteristics throughout 20,000 to 40,000 miles of vehicle operation.

The fundamental characteristics of friction materials are listed in Table 1. Friction level must be adequate and stable over a wide range of operating speeds, application pressures, and temperatures, regardless of the conditioning and age of the material. Of particular interest are the fade/recovery characteristics; i.e., the ability to resist friction level deterioration when subjected to extreme elevated temperatures (the fade) and then to return to the pre-fade friction level on cooling (the recovery). The friction material must have good wear properties for long life, but it must also not cause excessive wear or grooving on the mating disc or drum. Excessive compressibility, noise and roughness (chatter, vibration, pulsation) must be avoided, and sensitivity to moisture must be minimized. Finally, the friction material must be capable of being manufactured with consistency at a reasonable cost.

Detailed definitions of these characteristics, and their interaction and interdependence, have been discussed at length by Aldrich and Jacko.[1] In general, attempting to improve upon one characteristic often results in the deterioration of other characteristics. The development of friction materials is therefore a complex, interactive process seeking an optimized combination of interdependent characteristics.

The existence of numerous brake designs provides another level of complexity in designing friction materials. Linings for drum brakes require a wide range of properties. The duo-servo drum brake (the most popular U.S. design) requires two different types of linings, designated primary and

TABLE 1. CHARACTERISTICS OF FRICTION MATERIALS

Friction

- Level (coefficient)
- Stability - speed
  - pressure
  - temperature
  - conditioning
  - age
- Fade/recovery

Wear

- Friction material
- Drum or disc

Noise

Roughness

Moisture sensitivity

Manufacturability

- Processibility
- Uniformity

secondary, each of which needs different properties of strength, wear resistance, friction level and friction stability. The non-servo drum brake (used on many sub-compact vehicles) requires a friction material which encompasses the best characteristics of the primary and secondary in a single formulation, with emphasis on low-temperature properties and static friction capability. The large hydraulic and air-operated drum brakes utilized on medium and heavy trucks require, in general, the maximum properties of the smaller vehicle linings but at significantly higher operating temperatures. The arcuate form of drum brake linings places additional restrictions on the formulation, because of processing requirements.

Disc brakes demand a totally different set of operating conditions for the friction materials. Disc brakes generally operate at significantly higher temperatures than equivalent drum brakes, and the front disc brakes run hotter than the rear drum brakes on the same vehicle (Table 2). The friction material for disc brakes must be specifically designed for these higher temperatures, and must possess a higher coefficient of friction and better wear characteristics across the temperature range. Friction-material formulations must also be tailored to the specific needs of the particular vehicle application. Numerous parameters such as vehicle weight, front-to-rear brake balance, actuating system design, and duty cycle affect the capability of a particular lining formulation to perform satisfactorily.

The existence of numerous complex performance standards emanating from consumers, associations, manufacturers, and government agencies provides an additional set of parameters that friction materials must meet. Significant differences can exist between friction materials used as original equipment in new vehicles and friction materials available as replacement parts in the aftermarket. Each vehicle manufacturer has a unique, extensive set of test and acceptance standards to ensure the safety, durability, and performance of its products and the components used therein. Government-instituted requirements exist at the federal, state, and local levels. Federal requirements include those promulgated by the Department of Transportation (vehicle performance), the Occupational Safety and Health Administration (manufacturing work practices), and the Environmental Protection Agency (manufacturing practices and raw materials).

In order to meet the many characteristics outlined thus far, friction materials for automotive brakes have developed as complex composites containing three general types of ingredient materials: reinforcing fibers; modifiers that adjust or maintain friction level; wear rate and noise properties; and organic resin binders. Historically, the type of friction materials used in most automotive applications has been conventional organic friction material. The foundation or major constituent of conventional organic friction material has been asbestos fiber, so chosen because of its unique combination of characteristics. Asbestos fibers provide reinforcement, possess a high coefficient of friction, and more importantly, have excellent thermal stability. The openness of the fiber, its adsorptiveness, and its compactability enhance the processing and uniformity requirements. Finally, asbestos fibers have been available in a variety of grades at a relatively low cost.

TABLE 2. BRAKE FADE TEMPERATURES[a] (°F) (SUBCOMPACT FRONT WHEEL DRIVE VEHICLE)

	1st SAE fade[b] (10 stops)		2nd SAE fade[b] (15 stops)	
	Disc front	Drum rear	Disc front	Drum rear
Combination 1	780	300	870	360
Combination 2	985	235	1030	240
Combination 3	760	200	855	235

[a] Temperatures measured before the last stop. Actual temperatures for disc brakes are 80 to 180°F higher, as measured below the rubbing surface. Surface temperatures are in excess of 1600°F (870°C).

[b] SAE J843c

Once the friction material has been cured, the asbestos fibers are locked into the matrix. During brake operation, the high temperatures generated at the interface convert more than 99.7 percent of the asbestos to non-fibrous residues (primarily olivine) in the wear debris,[2] and less than 0.02 percent asbestos becomes airborne.[3,4]

The conventional organic formulations and the processes by which they are made have been dependent upon and tailored to the physical and chemical properties of asbestos. Two courses of action are open for elimination of asbestos from automotive friction materials:

1. Develop a new generation of friction materials, designed from the start without asbestos in mind.

2. Attempt to substitute an alternative fiber system for the asbestos in conventional formulations, with subsequent modification of composition and process techniques.

Bendix is aggressively pursuing both courses of action. As Mr. William Agee, our Chairman and Chief Executive Officer, has stated, Bendix is committed to being asbestos-free at the earliest possible date within this decade.

SEMIMETALLIC DISC PADS

Properties

In the 1960s, a new generation of friction materials, called semimetallic, was developed to meet severe braking requirements which organics could not meet. Class A organics (typical U.S. materials), which perform well in low and moderate temperature duty, are prone to fade and exhibit compressibility and poor wear resistance at high temperatures. Class B organics (typical European and Japanese materials) provide good high-temperature wear and friction levels, but have poor low-temperature wear resistance, produce rotor scoring and/or wear, and are prone to being noisy. Semimetallics were initially develed for these extreme, high-temperature applications.[5]

Semimetallics rely on steel fiber and powder metallurgy techniques for reinforcement. Various property modifiers are added to enhance performance to desired levels, with a resin binder holding the materials in a uniform solid mass. Semimetallics may contain metallic powder, sponge iron particles, ceramic powder, steel fiber, rubber particles, graphite powder, and phenolic resin.[6,7] Some manufacturers utilize a backing layer of a different composition which can contain asbestos.

Problems Overcome

Inherent in the uniqueness of the semimetallic formulations and their performance properties were a number of significant problems which required resolution. Concentrated development effort was required to resolve both processing and performance related issues. Processing issues included: the uniformity of the raw materials mixtures, the ability to form and handle the in-process material, and the ability to manufacture high-quality parts consistently.

Performance issues included: materials strength, cold friction properties, initial wear resistance, and attachment to the backing plate. The development effort on semimetallic friction material has been continuous, not only to further improve its characteristics and properties, but also to overcome the problems inherent in accommodating new vehicle applications.

Semimetallics gained acceptance because they were able to solve some of the problems that could not be overcome using Class A or Class B organics. The improvements/advantages are listed in Table 3. The key element is the attainment of overall excellent properties at both low and high temperatures. Semimetallics cost more because of more expensive ingredients and a costlier process, but the improved performance capabilities offset these factors. An increased usage of semimetallics has occurred over the past few years. The downsizing of vehicles, with resulting smaller front brakes and higher operating temperatures has given impetus to increased use of semimetallics.[8] It is expected that the trend toward asbestos-free semimetallic disc pads will continue.

SEMIMETALLIC DRUM LININGS

An obvious alternative to conventional organic drum brake linings is the use of semimetallic material for drum linings. In fact, one of the first applications for semimetallics was for air brakes on heavy-duty trucks used in the logging industry--an extremely severe application.

Significant development effort has been expended on semimetallic drum brake linings. However, the basic nature of semimetallics does not lend itself to the arcuate segment configuration required for small drum brakes. The semimetallic mix does not possess the necessary green strength, is difficult to bend into the arcuate shape, and is more brittle in its cured form and therefore subject to cracking. Modifications to the formulation to facilitate processibility generally result in a product that cannot achieve commercially acceptable performance characteristics.

These difficulties present a clear challenge, and development work on semimetallic drum brake linings continues.

ALTERNATE FIBERS/REINFORCERS

Properties

Alternative fiber systems in conventional organic formulations represent the second course of action open to friction-material manufacturers. Table 4 is a summary of the properties of some of the various materials which could be considered as alternate reinforcements. Since conventional organics and semimetallics have traditionally been reinforced with asbestos and steel fiber, respectively, these fibers are also included in the table for comparative purposes. The data in Table 4 were obtained from the material manufacturer's literature and extensive characterization data developed at Bendix. Characterization included scanning electron microscopy and x-ray energy spectroscopy (SEM/XES). The selection of suitable alternate materials must also consider

TABLE 3. IMPROVEMENTS OFFERED BY SEMIMETALLIC DISC PADS

- Improved energy absorption
- Fade resistance
    - Temperature insensitivity
    - In-stop fade
    - Speed spread
- Friction stability (FMVSS 105-75)
- Higher temperature capabilities (life)
- Rotor compatibility
    - Scoring
    - Heat checking
- Reduced noise
- Smaller brake sizing

TABLE 4. CHARACTERISTICS OF REINFORCING AGENTS

NAME	ASBESTOS	FIBERGLAS 497	MINERAL FIBER	SUZORITE MICA	FIBERFRAX (CHOPPED)	WOLLASTONITE	FRANKLIN FIBER	GRAPHITE WFA	CARBON WFA	SOLKA-FLOC	KEVLAR 29	STEEL FIBER
MANUFACTURER	JM, etc	OWENS/CORNING	U.S. PIPE AND FOUNDRY	MARIETTA RESOURCES	CARBORUNDUM	MINED BY INTERPACE (NY)	CERTAIN TEED	UNION CARBIDE	UNION CARBIDE	BROWN CO.	DUPONT	AMERICAN STEEL WOOL
COMPOSITION (WEIGHT PERCENT)	$3MgO.SiO_2.2H_2O$ SiO_2 MgO	E GLASS SiO_2 54.5 Al_2O_3 14.5 CaO 17.0 MgO 4.5 B_2O_3 8.5 Na_2O 1.0	SiO_2 42 Al_2O_3 8 CaO 35 MgO 8 Other 7	SiO_2 41 Al_2O_3 16 MgO 21 K_2O 10 FeO 8 Other 4	SiO_2 47 Al_2O_3 51 Other 2	$CaSiO_3$ $CaO.SiO_2$ SiO_2 51 CaO 47 Other 2	$CaSO_4$ WISKERS	99.5% C	91% C	CELLULOSE	AROMATIC POLYAMIDE 100% ORGANIC	SAE 1010 C 0.1 Mn 0.4 S 0.1 Fe 99.4
COST (¢/LB)**	1.0	5.0	1.9	0.8	5.9	1.0	0.8	98.9	29.6	1.2	19.8	2.7
SHAPE	FIBER	FIBER	FIBER	PLATE	FIBER	FIBER	FIBER	FIBER	FIBER	FIBROUS	FIBER	FIBER
LENGTH (μm)	250+	3175+	28	3175+	305	-	50+	6350+	6350+	76	6350+	800-2000
DIAMETER (μm)	0.25*	13	1-10	-	2	-	2	8.4	11	18	15	80-100
ASPECT RATIO	10,000+	240+	40-60	-	150	15	25+	750+	575+	4	423+	10+
SPECIFIC GRAVITY	2.56	2.6	2.7	2.7	2.73	2.9	3.0	1.4	1.4	1.4	1.45	
TENSILE STRENGTH (PSI)	280-440 KPSI	450-550 KPSI	3-20 KPSI	33-37 KPSI	400 KPSI	-	300 KPSI	120 KPSI	30 KPSI	-	400 KPSI	-
AVG:	360 KPSI	500 KPSI	70 KPSI	-	-	-	-	-	-	-	-	-
THERMAL STABILITY:												
UPPER USE TEMP (°F)	1200	1300	1400	-	2300	1200	1800	1200	1000	~400	700	~1000 F
T_g (°F)	-	1350	1400	-	-	1200 (tr)	2100 (tr)	-	-	-	-	-
T_{fus} (°F)	-	2000	2300	2960	-	1540	2600	-	-	-	-	~2500 F
Td (°F)	1600	-	-	-	-	-	-	-	-	-	800	-
HARDNESS (Mph)	3.0 - 4.0	6.5	6.0 - 6.5	2.5 - 3.0	7.0 - 7.5	4.5	~3.5	~1.0	~1.0	1.0	1.0	5.5
MISCELLANEOUS INFORMATION		SILANIZED	ALSO MINERAL WOOL			SILANIZED FORM AVAILABLE	SLIGHTLY SOLUBLE IN WATER 0.1 gm			5.7% MOISTURE		

*Fibril Diameter
**Relative to asbestos.

the health and safety implication of the substitute fiber system. After considerable study of existing information, Bendix has chosen substitute materials which, in our judgment, are free from serious health implications.

Processing Conditions

Current organic friction materials have been developed around the unique properties of asbestos. Asbestos fiber bundles open during mixing and entrap the friction modifiers and resin, giving a consistent mix. The compactability of asbestos facilitates forming at room temperature with moderate pressure.

The non-asbestos fibers are much more difficult to handle. Most are very brittle and have little or no surface adsorptivity. High bulking and segregation occur during mixing. Spring back and low tack lead to weak structures. Combinations of additives and new processing techniques are required to overcome these problems and produce the cohesiveness necessary for manufacturing parts.

Performance Characteristics

The characteristics of the fibers can have significant influence on the performance properties of the final composite. Asbestos has a high, stable friction level, good adsorptivity for strength and wear resistance, and does not contribute to noise.

Substitute fibers generally show greater frictional instability, little or no surface adsorptivity, and/or significant contribution to both noise and mating-surface degradation.

NON-ASBESTOS ORGANIC DISC PADS

Failures on Direct Substitution

A commercial Class A organic disc pad formulation, similar to one reported earlier[9] and known to contain phenolic resin, asbestos fiber, organic friction particles (cashew and rubber dusts), zinc chips, and barytes was selected as a baseline composition. In a series of new formulations, the asbestos fiber was replaced with glass fiber, mica, mineral wool, Franklin fiber, a glass fiber/mica mixture, a glass/Fiberfrax/graphite fiber mixture, and a glass/Wollastonite fiber mixture.

The composites were run on an inertial dynamometer equipped with a Bendix-designed Series III disc brake loaded to 1000 pounds. Stops from 50 mph (80 kmph) at 3.66 mpsps (12 fpsps) deceleration were run at different initial brake temperatures up to 315°C (600°F). All fiber substitutions produced roughness followed by poor friction. Generally, the composites were structurally inadequate producing tear-out and poor wear resistance, in addition to roughness (Table 5). All formulations were considered failures. This led to the conclusion that simple direct substitution of alternative fiber systems was not practical.

TABLE 5. DIRECT SUBSTITUTIONS AND THEIR FAILURES

Formulation	Reinforcement	Strength	Performance
Baseline	Asbestos	• Strong No defects	• Stable friction Good wear resistance
b,c,e	Glass	• Pad surface tearout	• Erratic friction, fade, high pad wear, and scored rotor
d	Mica	• Pad surface and edge tearouts	• Good friction, SL fade, high pad, and rotor wear
f	Glass/Mica	• Weak	• Poor friction, fade, and inner pad wearout
g	Glass/Fiberfrax/Graphite	• Strong	• Roughness, fade, acceptable pad wear, and scored rotor
h	Glass/Wollastonite	• Pad surface tearout	• In-stop fade, acceptable pad wear, and scored rotor

Alternate Approach

A new baseline was selected with increased reinforcement content to better screen the following characteristics:

- processing
- strength
- performance (friction, wear, drum compatibility, and noise properties)
- cost

The initial objective was improved structural capability. A number of formulations were made using high fiber concentration. As shown in Table 6, the tensile strength results were very encouraging. The next step, which proved very difficult, was attaining a proper balance of friction and wear to go along with the strength.

Sample Dynamometer Results

A series of combinations of materials with a fixed ratio of glass fiber and the other reinforcements was evaluated on a sample dynamometer (Table 7). The results indicate that all of these reinforcement combinations are poor substitutes for asbestos fibers in that they exhibit poor friction, poor wear resistance, poor friction stability, or poor rotor compatibility. However, some clues were provided and it was possible to combine two of the formulations to produce a new composite M. This material was then reformulated with additional property modifiers in six other iterations to produce yet another formulation S, which exhibited a high but stable friction coefficient, equivalent wear resistance, and slightly poorer rotor wear resistance. At this point, the study was transferred to full brake inertial dynamometer testing.

Inertial Dynamometer Results

The inertial dynamometer confirmed that formulation S had a higher friction level, slightly better wear resistance, and slightly poorer rotor compatibility than the baseline (Table 8). Approximately 40 iterations of formulation S led to formulation AA which gave good friction with friction stability and very good wear resistance. Further iterations (~10) led to formulation AL which gave lower friction, poorer wear, and good rotor compatibility. In addition to inertial dynamometer tests, a series of vehicle tests was also initiated.

Vehicle Test Results

Several formulation iterations were coupled with processing improvements. Formulation DA was developed after approximately 50 iterations following Formulation AL. Formulation DN was developed after 13 iterations of a new-concept material which has been patented.[10] The vehicle test results (effectiveness, fade, and recovery, in addition to wear data and noise ratings) are given in Table 9 and were run according to a modified SAE J843c schedule. Formulation Bendix D7180 is a Class A organic used as the baseline.

TABLE 6. TENSILE STRENGTH DATA

		Tensile strength (psi)		
Formulation	Reinforcer	Min.	Avg.	Max.
Baseline	Asbestos	3100	4000	4600
A	Glass fiber	3400	4800	6350
B	Mineral fiber	600	1300	1850
C	Wollastonite	850	1500	2350
D	Suzorite mica	850	1400	1750
E	Glass[a]	2750	3500	3750
B^1	Silanized mineral fiber	2900	3150	3250

[a] Reduced content.

TABLE 7. SAMPLE DYNAMOMETER TEST RESULTS

Formulation	Reinforcer(s)	250F		450F		650F		250R[b]		Rotor Wear
		μ	W[a]	μ	W	μ	W	RF	RW	
Baseline	Asbestos	0.32	0.002	0.28	0.004	0.30	0.022	1.00	2.62	0.0000
A	Glass fiber	0.32	0.005	0.23	0.010	0.16	>0.080	1.31	1.70	0.0003
F	WOL/GF	0.33	0.004	0.34	0.009	0.16	>0.040	1.16	1.68	0.0003
G	Mica/GF	0.49	0.004	0.19	0.010	0.22	>0.060	1.08	2.31	0.0001
H	MF/GF	0.32	0.004	0.17	0.012	0.16	>0.080	1.37	-	0.0001
J	FRAX/GF	0.36	0.009	0.45	0.013	0.50	>0.200	-	-	>0.0005
K	FF/GF	0.36	0.003	0.50	0.005	0.32	0.016	1.75	2.07	0.0001
L	SOFL/GF	0.35	0.002	0.18	0.003	0.18	>0.080	-	-	0.0000
M	Proprietary	0.35	0.002	0.22	0.003	0.18	-	1.20	1.12	0.0001
S	Proprietary	0.45	0.002	0.45	0.006	0.46	0.018	1.04	2.27	0.0001

[a] All wear figures are in inches

[b] Rerun used to provide relative friction (RF) and relative wear (RW) trends after high temperature operation.

TABLE 8. INERTIAL DYNAMOMETER TEST RESULTS

	Burn		300F		450F		600F		300F		Rotor
	LP[a]	W[b]	LP	W	LP	W	LP	W	LP	W	W
Baseline	380	0.004	660	0.003	700	0.009	490	0.028	470	0.007	0.0000
S	400	0.003	400	0.003	300	0.008	280	0.018	-	-	0.0007
W	400	0.003	400	0.003	350	0.007	300	0.015	-	-	0.0004
AA	400	0.002	370	0.002	340	0.006	390	0.008	440	0.003	0.0003
AD	420	0.003	650	0.003	600	0.012	450	0.037	330	0.006	0.0002
AL	440	0.003	510	0.002	580	0.008	430	0.034	270	0.004	0.0000

[a] All line pressures are in psi.

[b] All wear figures are in inches.

TABLE 9. VEHICLE TEST RESULTS (1977 FULL SIZE STATION WAGON LOADED TO 5540 LBS)

	Class A organic		Non-asbestos organics			
	D7180		DA		DN	
Fronts*	30 MPH (48 KMPH)	60 MPH (97 KMPH)	30 MPH (48 KMPH)	60 MPH (97 KMPH)	30 MPH (48 KMPH)	60 MPH (97 KMPH)
Preburnish effectiveness**						
Full system	500	500	440	460	440	400
Post-burnish effectiveness**						
Full system	600	600	520	530	500	420
Fronts only	1180	970	1020	900	620	620
First SAE fade (10 stops)**						
Max	-	1100 Max	-	1000 Max	-	1000
(Recovery - 10)	(410)	-	(380)	-	(320)	-
Second SAE fade (15 stops)**						
Max	-	800 Max	-	800 Max	-	880
(Recovery - 10)	(410)	-	(360)	-	(340)	-
Post-fade effectiveness**						
Full system	600	500	450	460	420	460
Fronts only	900	670	960	850	700	920
Wear (Mils)						
Burnish (F/R)	6/6		11/9		11/6	
Fades (F/R)	42/3		33/3		22/2	
Total pads (F/R)	48/9		44/12		33/8	
Total rotor	0		1.0		1.5	
Noise ratings						
Fronts	10		8		6-8	
Rears	10		10		10	

*All tests used same rears (BX4641A/H3133).

**Line pressures needed for 15 FPSPS deceleration per SAE J843C.

The line pressure data show that the non-asbestos organics have higher preburnish, post-burnish, and final effectiveness than the baseline, based on full-system as well as fronts-only checks. This higher friction level and friction stability are also demonstrated in the fade and recovery portions of the test.

Both non-asbestos organics showed poorer burnish wear resistance, and both showed improved wear resistance during the fade and recovery portions of the test. The rotor compatibility of both non-asbestos organics was poorer than that of the asbestos-based baseline.

Formulation DA, which is more typical of Class A organics, showed less loss in rotor wear than did the new-concept DN material. Both materials were prone to be noisy.

Status

Non-asbestos organic disc pads are still in the development stage because several problems have not yet been resolved:

- rotor compatibility
- wear durability
- noise properties
- processing

Bendix is continuing development efforts to commercialize non-asbestos, organic disc pads.

NON-ASBESTOS ORGANIC DRUM BRAKE LININGS

Process Characteristics

Drum-brake linings require different processing characteristics than do disc pads. When made by a wet process technique, friction materials require a binder-wetted plastic mass with good cold flow properties. When made by a dry process technique, they require good hot flow properties, but must first be capable of being preformed under cold pressure conditions to develop strength for handling purposes. Both wet and dry process types require the capability of ultimate arcuate formation. All currently known alternate fibers result in serious problems in these areas.

As in the case of disc pads, the direct substitution of alternate fiber in existing asbestos formulations has been unsuccessful. Basic processibility has been the first obstacle. The generally stiff, nonabsorptive alternate fibers do not result in a wetted, densified mass. This precludes cold-pressure forming into brake-lining strip configurations typical of wet process methods. In the case of dry-process methods, the fiber stiffness is a deterrent to good physical integrity of preforms and also leads to excessive lining cracking during bending. In general, the alternate fiber materials do not result in a mix character which allows them to be processed effectively by currently known techniques. The solutions to these problems call for radically different approaches to material formulation and processing techniques. The new processing techniques require substantial capital investment.

Testing and Development

With the application of suitable material and process changes, non-asbestos type drum linings have been experimentally fabricated and tested. Hundreds of formulations of duo-servo primary linings and secondary linings, along with those for non-servo type brake linings, have been made. When processed satisfactorily, these materials have been tested on sample dynamometers and inertial dynamometers before selecting the better ones for vehicle testing. The use of different formulations to overcome the process problems has resulted in substantially different frictional and wear characteristics which have had to be modified to duplicate current materials more closely.

Table 10 illustrates the magnitude of some of the early problems and some of the later results. Initial tests using very high friction combinations (A and B) run on Vehicle 1 with a front-brake hold-off valve, resulted in a serious duty shift with front brakes projecting greater than normal mileage, and the rear brakes projecting short life because of their higher work load. However, when Combination A was run on Vehicle 2 (which had no front-brake hold-off valve), the secondary lining (the same as in Combinations A and B) projected almost the minimum requirement of 15,000, although the primary gave only 7900 miles. Subsequent tests of improved combinations, particularly with improved primary lining life, projected over 20,000 miles. Tests on Vehicle 3, again without a front hold-off value, projected reasonably good life on Combinations E, F, G, and H, with quite acceptable life on the more recently developed Combination H. A comparison of wear projections on Combinations F and G shows the importance of primary-secondary teaming. Both combinations had the same primary, but with different secondaries, the life of the primary decreased from 20,900 to 12,200 miles.

The above data illustrates that basic life and performance are achievable, at least on certain vehicles. However, the materials noted above were prepared by more involved, more expensive processes and are noisier than current asbestos types, and the mating surface condition requires further improvement. Further, the ability of these materials to withstand extended in-service usage must be evaluated in a wide range of vehicle applications and environments.

Status

The first generation of asbestos-free drum linings is being evaluated by some vehicle manufacturers. Bendix is continuing development efforts on further improved materials.

ECONOMIC IMPACT

The economic impact of eliminating asbestos from automotive friction materials is significant and includes three distinct segments:

TABLE 10. LIFE TESTING ON VEHICLES

	Rear lining combination*	Front disk	Rear drum brake	
		Pad life (miles)	Primary life (miles)	Secondary life (miles)
Vehicle 1	A	59,600	3,700	8,200
	B	44,500	6,600	5,900
Vehicle 2	A	31,400	7,900	14,500
	C	33,200	20,700	26,800
	D	27,600	28,300	20,400
Vehicle 3	E	31,100	17,600	15,900
	F	34,800	20,900	16,900
	G	28,100	12,200	18,700
	H	21,450	32,800	27,400

*Same type front disc pads for all tests.

1. Research and Development/New Capital Investment: Bendix has committed, and will continue to commit, extensive funding to both research and development efforts and to the new equipment and facilities required to support asbestos-free friction materials. Over the last 5 years, the number of dynamometers, and test vehicles at our Friction Materials Division has doubled, and engineering headcount has been increased by over 60 percent. The total engineering budget has tripled, and the share of the budget devoted to asbestos-free product development has grown from 13 percent in 1976 to over 71 percent for 1981. The corporate research laboratories have also expended significant effort in support of the division. Based on our current plans, Bendix estimates that it will have committed over $25,000,000 to engineering activities on asbestos-free product in the U.S. by 1985.

   Capital expenditures must also be increased significantly. Over the next 5 years, the average annual expenditure related to asbestos-free products will be triple the historical average annual expenditure for the entire division. Based on our current plans, Bendix estimates that it will invest over $60,000,000 (1980 constant dollars) in new equipment and facilities for asbestos-free products.

2. Product Cost: The basic cost of the product itself is a complex function involving many factors. The amount and types of materials used, and the basic raw materials cost are obvious factors. The fixed and variable costs of manufacturing can differ greatly, based on the type of process and its complexity, production volumes, labor costs, energy cost, and process yield, among other factors. Administrative costs and handling/distribution costs are also significant variables.

   Preliminary cost estimates indicate that asbestos-free drum brake linings may cost 20 percent to 50 percent more than current linings. Disc brake pads may cost 20 percent to 100 percent more than current materials. These estimates are for products delivered in the original equipment market. We emphasize these are preliminary estimates. Until parts can actually be manufactured on production equipment in significant volumes, costing estimates must be preliminary. The estimates are highly dependent on the raw materials and processing techniques, which can vary significantly. Moreover, research and development continues, and future results can affect product cost.

3. Implementation Costs: As noted earlier, vehicle manufacturers have an extensive series of stringent test requirements. Each different vehicle configuration requires the series of tests to ensure that the product conforms to the requirements. Since asbestos-free materials may have some performance or property differences from current materials, vehicle system redesign may be necessary. We do not have sufficient information to accurately estimate costs associated with the test programs. We

would expect that each vehicle manufacturer would expend millions of dollars, and possibly tens of millions, in converting their product lines to asbestos-free materials. A key element is the timing of the test programs. Expenses could be minimized by converting to asbestos-free materials as part of the scheduled new vehicle design programs, where significant brake-system testing is already necessary.

TIMING

Friction materials development is a lengthy process. As mentioned previously, the materials themselves and their properties are the results of optimization procedures, and the necessary testing programs are extensive. These programs include not only testing by the friction material supplier to develop and document the materials' capability, but also extensive testing by the customer to ensure suitability and regulatory conformance in the particular application.

Historical data gives us a sense for program timing. Evolutionary changes generally require 18 to 24 months for supplier development and validation testing, and 6 months manufacturing lead-time--that is a total of 3 to 4 years. An example of such a change would be an improved organic disc pad utilizing the same basic components (i.e., asbestos, resin, modifiers). Compared to its predecessor, the new formulation might exhibit 15 percent better wear, improved fade resistance, and the same friction and noise properties. Today's asbestos organic linings are essentially the product of 40 years of evolutionary changes.

Revolutionary changes, which advance the state of the art, are more difficult to come by. It is unrealistic to put a timetable on invention, but establishing the feasibility of a new concept can take 12 to 18 months. Reducing that concept to a product with some or most of the basic characteristics can take 12 to 24 months. Formulation development to obtain a balanced set of characteristics for commercial application, and validation of those properties requires 24 to 36 months. As before, 12 to 18 months for customer application testing, and 6 months manufacturing lead-time are needed--that is a total of 5½ to 8½ years. The semimetallic discussed previously is a good example.

Semimetallic development began in 1962. The first low volume, special-purpose applications occurred in 1969. General acceptance came in the mid 1970's with the second generation of semimetallic formulations. Today, semimetallic disc pads are utilized on the front brakes of approximately 50 percent of the new vehicles built in the U.S., and projections approach 100 percent utilization by 1985. It has taken continued development and improvement of semimetallic properties to achieve this level of use.

The elimination of asbestos from automotive friction materials must be considered a revolutionary change. There are strong indications that the asbestos-free materials can achieve general acceptance more rapidly than semimetallics did. However, basic development needs demand a minimum time from the start of a program to initial production and application. Assuming a 1975 start date, historical data would suggest that initial applications could be expected in the 1982/83 time frame, and we believe that we are close to that timetable. However, this only applies to the first generation of asbestos-free materials. Continued engineering effort (evolutionary changes) will be required to develop both the second generation of materials with improved properties, and the multiplicity of types of formulations necessary for different applications.

As indicated earlier, semimetallic disc brake linings containing no asbestos in either the friction material or the backing layer are in use today. It should be pointed out that the semimetallic friction materials have some characteristics which may preclude their utilization in certain vehicle applications. An orderly transition to significantly increased utilization of semimetallic disc pads on new U.S. vehicles is in process, and will probably approach 100 percent utilization no later than 1985.

Development continues on both asbestos-free organic disc-brake linings and on semimetallic drum brake linings, but the timing for production implementation cannot be accurately predicted.

The initial generation of asbestos-free organic drum-brake linings is in the final development stage at Bendix, and initial evaluations are underway at vehicle manufacturers. Some asbestos-free blocks are available commercially for heavy truck applications. While it is too early to tell whether these formulations will achieve commercial success, the first significant production release would probably be in 1982.

Although this presentation has primarily addressed original equipment considerations, the use of asbestos-free materials in the automotive aftermarket will create additional challenges. As new vehicles are produced with asbestos-free friction materials, they should be serviced with asbestos-free products. However, since the asbestos-free materials may very well have property and performance differences compared to current friction materials, it may not be possible to substitute the asbestos-free materials directly in older vehicles without compromising safety. Hence, significant time and effort will be needed to evaluate the effect of new asbestos-free friction materials in aftermarket applications to ensure safe and efficient braking and adequate lining life prior to the release of these asbestos-free materials for use in the aftermarket.

SUMMARY

Automotive friction materials are complex composites that have developed around the properties of asbestos. There is no simple substitution for asbestos fibers in automotive friction materials. Extensive engineering programs are required to develop new asbestos-free formulations and process techniques, and to conduct testing to ensure the adequacy and safety of the new friction materials.

Semimetallic disc pads, originally developed for heavy duty applications, meet the criteria of being asbestos-free and are in use today. The trend toward significantly increased usage is well established. The first generation of asbestos-free drum linings for passenger cars and light trucks is in the final stages of development at Bendix, and in the initial stages of evaluation by vehicle manufacturers. If these asbestos-free drum linings prove to be commercially acceptable, initial limited production usage could occur as early as 1982. Some asbestos-free friction materials are currently available on the market for heavy truck applications.

Engineering programs continue on improved versions of the materials mentioned above, and also on other types of materials which might prove successful. Bendix is committed to developing asbestos-free alternatives, and an orderly transition to such materials is now taking place. Significant engineering effort and time is needed to accomplish this transition.

As stated in the Bendix Corporation's 1979 annual report, "...Bendix early in the 1980's will offer its automotive customers brakes made with long-wearing high-performance friction materials that are asbestos-free." We intend to meet that commitment.

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DISCUSSION ON FRICTION PRODUCTS

QUESTION (Chairman Guimond): You discussed quite a bit relative to the work that has to be done in research and development and the cost involved in equipment. In discussing the increased costs, that is 20 to 50 or 20 to 100 percent, depending upon what product line you were talking about, did these increased costs reflect research and development in the capital equipment writeoffs? And secondly, could we also anticipate, that as you learn more about manufacturing that the relative costs would come down?

ANSWER (Mr. Brunhofer): As I tried to indicate in the presentation, we separated the cost discussion into three segments. The first was research and development and capital, and since we discussed those costs under that topic, we felt it would not be fair to also include amortization of those costs when we talked about product cost; therefore, we did not include research and development costs or capital. We simply looked at the manufacturing process and the types of materials, as best we could identify them, and did cost studies on the cost of the materials.

Part of the variance that we put into the discussion of increased costs has to do with estimates on what our effectiveness will be as the process gets started. Obviously, with semimetallic materials, there is a significant body of knowledge available. The variance there, as I tried to indicate, is more with respect to what the base line material is, as opposed to any new process development. But in the area of drum brake linings, where we feel we are close, and in the area of semimetallic drum and substitute fiber disks, we simply do not have any method of running production materials at this time. The capital equipment is on order, but it is not in place, and until we get those lines running, it is very difficult to come up with firm numbers.

QUESTION (Mr. Fenton): I am from Marietta Resources. To what extent have you been codeveloping, or working with any of the suppliers who may be competent or able to modify drum brake linings?

ANSWER (Mr. Brunhofer): We have worked with suppliers. We recognize the fact that their knowledge as to treatments of materials for our specific application can be very helpful. Other than that, it is a source of information we have used and we will continue to use and look forward to anything that anyone might have to offer in that area.

QUESTION (Mr. Wing): I represent Dow Chemical, which neither makes brake linings nor any components that go into them, so my concern as a citizen is the cost of regulation. Based upon the Bendix report, I believe there is about one ton of airborne asbestos, produced annually from passenger cars, and a total of about three times that amount, scattered over an area of about 3,000 miles by 2,000 miles. I cannot conceive that that presents an unreasonable risk, so why are we even talking about substituting asbestos?

ANSWER (Chairman Guimond): No, I would rather not get into the bad or the good points of why we should or should not regulate asbestos at this stage from the standpoints of a health hazard. Clearly, there are problems with the various occupational exposures; but nonetheless, we appreciate your comment.

QUESTION (Mr. Castleman): I would like to know if you deal in international as well as domestic markets, and what interest is there from foreign automobile manufacturers and foreign governments in products that you talked about today?

ANSWER (Mr. Brunhofer): In answer to your question, yes, we do deal in international markets. Most of what I have addressed today has to do with the business of the Friction Materials Division of Bendix, which is the U.S. operating arm. Bendix also has divisions involved in friction materials worldwide. Those divisions also have programs with respect to friction materials in their own market places and with their own customers.

There is international interest. For a while, the interest in the U.S. was more intense than the interest in Europe; then for a period of time, the interest in Europe became very intense. There are materials under evaluation in Europe. The Japanese have been interested.

We have tried to work with our customers (vehicle manufacturers) to keep them informed of the situation as we see it, and that does include not only the U.S. and U.S. auto makers but also international markets, both as they pertain to those marketplaces themselves and the products that may come into the U.S.

QUESTION (Mr. Castleman): At this point is the United States at the leading edge, in commercially developing and using the substitutes or do you find there are other countries that are in an equivalent position today?

ANSWER (Mr. Brunhofer): I am not really an expert in that area. Just from top-of-the-head knowledge, I would say the European market is about even. As I understand the European market right now, it is roughly at the state where there are products that are being evaluated by the suppliers and by the vehicle manufacturers. I believe in one or more of the Scandinavian countries there is legislation that either severly limits or totally bans the use of asbestos. I am not 100 percent positive in that area.

QUESTION (Mr. Moon): I am with Jim Walter Research Corporation. I would be interested in knowing what kind of criteria you use in looking at substitute fibrous material? What kind of health information do you require in evaluating substitute fibers? Is it specific or is it general?

ANSWER (Mr. Brunhofer): Some of it is rather specific; some if it is obviously general. Primarily, we have looked at the information available in the literature. We have worked with the suppliers. One of the things we have special concerns about is fiber size. We feel it is a very important issue and we have made some judgments as to what size fibers we will and will not use. And that is one of the restrictions on any fiber that we will consider. Obviously, a second very important aspect is the capability to withstand severe use and that eliminates many fibers. We also have some concerns as to what is going on at the fiber surface. We are seeing extremely high temperatures at the surface. We wonder what the byproducts might be of some of the substitute materials, and this is an area that I think is in its infancy. I do not want to be more specific than that but those are some of the considerations.

GASKETS AND PACKINGS

by

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ABSTRACT

ALTERNATIVES TO ASBESTOS AS A BRAIDED PACKING MATERIAL

The advantages of asbestos packings are that they are strong, inexpensive, and are resistant to heat and chemicals. Disadvantages are that they are very abrasive and have poor heat dissipation. Substitutes for asbestos packings are available. To properly evaluate their performance, mechanical (pressure, velocity), chemical (acidity, causticity), and thermal (environmental, friction) factors must be compared to those of asbestos packings. The costs of non-asbestos packings might seem higher than those of asbestos packings. However, when maintenance and operating costs are considered, the newer synthetic packings are competitive.

GASKETING

Commercially available non-asbestos gasketing materials include vegetable fiber, cork composition, plastics, rubber, graphite, beater-saturation materials, and metals. Performance characteristics of these materials are discussed and compared with those of asbestos-containing gaskets.

ASBESTOS AS A BRAIDED PACKING MATERIAL AND ALTERNATIVES

Asbestos yarns are the most common materials used in the manufacture of braided and woven packing materials, used as sealing devices in fluid processing and fluid power equipment. Braided packings are technically compression packings, because of the manner in which they perform, the sealing function. Made from relatively soft, pliant materials, compression of jam packings consist of a number of rings which are inserted into the annular space (stuffing box) between the rotating member and the body of the pump or valve. By tightening a follower or packing gland against the top ring, pressure is transmitted to the packing set, expanding the rings radially against the side of the stuffing box and rotating member, effecting a seal.

Compression packings find their major uses in the process industries such as petro-chemical, paper and steel mills, and in services such as utilities, marine, water, sewage, food and nuclear power. They seal all types of fluids-water, steam, acids, caustics, solvents, gases, oil, gasoline and other chemicals--over a broad range of temperature and pressure conditions. They are used in rotary, centrifugal and reciprocating pumps, valves, expansion joints, soot blowers and many other types of mechanical equipment. There are dozens of manufacturers of compression packings and thousands of marketing outlets, when you consider the fact that the majority of compression packings are sold through local industrial distributors.

Compression packings are made up of two or three components. The most important component is the yarn, which is made up of fibers or filaments spun together to produce a material which can be braided to form the body of the packing. This yarn gives the packing shape and is the strength member of the packing. Asbestos is the most common base material of which yarn is made for braided packings. The other two components are the suspensoid which fills the interstices in the braid and acts as a blocking agent, and the lubricant which reduces the frictional drag of the body materials on the shaft, to reduce heat build-up and energy requirements to operate the pump.

Asbestos has been used as a body material for compression packings for four main reasons. First of all, it is a very strong material. It can withstand the mechanical beating and abrasive attack found within the stuffing box area of a pump. Second, it is highly resistant to chemical attack, holding up to fluids from pH of 2-14. Thirdly, it is temperature resistant. AAAA asbestos can withstand temperatures up to 1000F. Fourth, and probably the most important reason for its use today, is that it is a relatively cheap material. Raw asbestos yarn sells for less than $2.00 per pound, when purchased in large quantities.

The disadvantages of asbestos, from an application engineer's standpoint, are as great as the advantages. Asbestos is a mineral, mined from the ground in rock form. To get it to packing yarn form, the asbestos fiber is spun around a carrier filament such as cotton or TFE. Asbestos fiber is very abrasive, acting much like a grinding wheel, when the yarn is compressed against a rotating shaft (as in a stuffing box). The suspensoid and break-in lubricant protect the shaft for awhile, but eventually the raw asbestos contacts the shaft or sleeve, causing scoring and eventual destruction of the component with which it comes in contact. Unfortunately, this process is often aided by the untrained maintenance man, who overtightens the packing gland, to reduce the pump drippage. As he does this, heat builds up, because of frictional drag. We are all familiar with asbestos as an insulator, basically to hold the heat in or out of our houses. The same thing happens within the stuffing box--with disastrous results. The trapped frictional heat boils all the lubricant and suspensoids out of the packing. The built up heat then has no place to go but along the shaft, eventually overheating the bearings, causing a failure and shutdown of the whole pump for major repairs. To keep this from happening, all packing manufacturers and pump manufacturers recommend a fairly generous flow of pumpage to be allowed to leak past the asbestos packings, to provide a cooling flow, and also a fluid film for the packing to ride on rather than the metal surface of the shaft. In some cases, an outside source of cooling and lubricating fluid is injected into the stuffing box area, through a porous ring called a lantern ring.

In spite of the problems just described, a well-trained maintenance crew could get reasonable life out of a set of packing, or what they thought was reasonable life because they had nothing with which to compare. In the 1950's, the development of teflon, by DuPont, began the era of the synthetic packing yarn. Teflon covered a wide range of applications with a pH range of 1-14, temperatures up to 500 F, and shaft speeds up to 1200 FPM. Its heat dissipation is poor, and not only that, it expands when heated at a rate ten times higher than the metal around it. So for a different reason we get the same mode of failure. In the 60's and 70's, other synthetic packings were developed, the state-of-the-art now being the carbonaceous fiber packings.

Table 1 outlines the most important packing fibers in use today, showing their advantages, disadvantages, and most common usage. TFE impregnated Aramid fiber is becoming the most popular asbestos substitute for service within the pH range of 3-11, for temperatures up to 500°F, and for shaft speeds under 2000 FPM. Its strength and non-contaminating qualities account for its popularity in such industries as pulp and paper and waste water treatment. Another popular packing fiber is Graphite/TFE composite. Its wider pH range of 1-14, and greater heat dissipation, makes it more versatile than Aramid or pure teflon. Its only drawback is its color, which is gray, causing some concern where color contamination could be a problem. The carbonaceous fiber packings, as stated above, are the first choice for all-around service superiority. They cover almost any process fluid, except for the very volatile strong oxidizers, such as oleum, fuming nitric acid, aqua regia and fluorine. For this reason, these products are approaching truly "universal packing" status, and once their usage becomes widespread, the economics of scale will bring their costs within the range of the synthetics which preceded them.

Performance of Asbestos Substitutes

In the selection of a dynamic service packing, two important criteria are the PV and the pH factors.

The PV factor, which is the factor for mechanical conditions, is determined by multiplying the pressure on the stuffing box by the velocity of the shaft. The resultant PV factor will pinpoint a range of applicable packings.

PV Factor = Pressure on stuffing box (PSI) multiplied by velocity of shaft (FPM)

$$PV = 2/3 \text{ discharge pressure} \times \left(\frac{\text{RPM} \times \text{Shaft Diameter} \times 3.14}{12}\right)$$

TABLE 1. FIBER USAGE CHART

Fiber	Advantages	Disadvantages	Most common usage
Asbestos	Heat resistant, pressure resistant, strong (tear resistance), availability, price.	Heat insulator, abrasive, health hazard, messy, low service life, fluid compatibility.	Depending on braid and lube: General service pumps, valves, etc.
Aramid	Super strong, tear resistant, flexible, lowest priced synthetic fiber, non-staining, long service life.	Hard to cut, cannot be die formed, 3-11 pH range 500 temp. limit.	Papermill-stock pumps hydrofiners, etc., sewage treatment plants-centrifugal sludge pumps, etc., all slurries in the 3-11 pH range. Possible future to replace all TFE/Asbestos.
Graphite/TFE Composite	Reduces run in time, chemical resistant, low thermal expansion, nonscoring, good heat dissipation, light weight (more feet/lb), not messy, nonstaining, flexible, will not extrude, a product you can standardize on. Great in valves, long service life.	If over tightened, it may glaze, possibly price.	Chemical pumps, especially effective on chemical slurries, sewage/slurries, general service.
TFE	Low friction, chemical resistance, nonstaining.	Thermal expansion, low shaft speed, 500°F limit, possible price.	Chemical pumps and valves, food and drug pumps and valves, nonstaining applications.
Carbon	Heat dissipition, takes high shaft speeds, least expensive in the carbon/graphite family, temperature resistant to 1200°F, operated with a lower drip rate, repack costs reduced total,removal not always necessary.	Brittle, possibly price.	The best boiler feed pump packing going especially the large ones in power plants, chemical pumps, boiler recirculating pumps, this is a good general power plant packing.
Graphite	Heat resistant, heat dissipation, fastest shaft speed, chemical resistance, long service life, light weight, near zero thermal expansion, near zero drip rate, a viable alternative to the mechanical seal, will not harden.	Brittle, frays, price.	In the dry form it is used in high temperature valves in power plants, high speed-low drip rate pumps, very hot chemicals, chlorine agitators, exotic high temperature and highly corrosive materials.

The Fluid Sealing Association has developed a chart showing this range, and it has been reproduced in this treatise as Table 2.

The pH factor is a numerical measurement of the intensity of severity of an acidic or caustic solution. This is the measurement of chemical attack which a packing will encounter. Tables 3 and 4 cover the pH values, and shows which packings are applicable to a specific pH factor.

The third criteria, equally important as the first two, is resistance to temperature. Aramid, Teflon and Graphite/TFE composites are generally limited to 500°F. Carbon Yarn is rated to 1200°F in steam or 650°F in oxidizing atmospheres. Pure Graphite goes all the way up to 6000°F in non-oxidizing atmospheres, 1200°F in steam, and 800°F in oxidizing atmospheres. An important factor to consider as far as temperature goes is frictional heat. If the surrounding atmosphere in which the packing must perform is close to the temperature limit of the packing (within 75-100°F), then careful attention must be paid to proper break-in of the packing, and maintaining adequate drip rates to enhance cooling and heat transfer away from the packing and delicate pump components. Even though packing materials such as graphite could withstand the heat, the crystalline structure of the metallic pump components could be altered, causing degradation and failure, or else oil seals and bearings may succumb to the heightened temperatures, also causing shutdown for major overhaul.

Table 5 represents an attempt to compare the various packing materials discussed in this treatise in some meaningful, practical way. It is titled "Experimental Preference Rating Chart", because the ratings are based on our experience in the field, and take into account more than just the three factors discussed previously. We have set up hypothetical examples of applications which could be found in almost any of the process industries. Service life of the packing, efficiency of energy usage, and equipment life are the three criteria which we give an experimental rating. One hundred is the highest a product can be rated and zero is the lowest a product can be rated.

The Economics of Change Over to Asbestos-Free Braided Packing

Braided packings are sold to the MRO user directly by the manufacturer and through industrial distributors on a per pound basis. Table 6 shows the comparative cost per pound of the most often used packing materials, in a ready to use braided form. Graphited and TFE impregnated asbestos represent probably 60-80 percent, in poundage, of all the heavy duty packings sold today. Even though braided packings are sold on a per pound basis, to understand the cost of using a specific packing, it is more relevant to talk about costs per packed stuffing box. Table 7 gives us this comparison.

Studying these charts, it would seem that there will be some economic hardship for the user to switch over to the asbestos-free packings. The truth is, that when all the costs are taken into account, the non-asbestos packing becomes the most cost effective alternative. The examples shown on Table 8 very clearly show that because of the superior life characteristics,

TABLE 2. PV FACTORS

Pressure	Surface velocity, FPM	PV factor	Stuffing box temp., °F	Aramid	Carbonaceous	TFE	Graphite/TFE composite
0-50 PSI	52-916	45,800	50-150	X	X	X	X
			151-500	X	X	X	X
			501-600		X		
			601-750		X		
51-100 PSI	916-1885	188,500	50-150	X	X	X	X
			151-500	X	X	X	X
			501-600		X		
			601-750		X		
101-174 PSI	916-1885	328,000	50-150	X	X	X	X
			151-500	X	X	X	X
			501-600		X		
			601-750		X		
175-250 PSI	916-1885	471,300	50-150		X		X
			151-500		X		X
			501-600		X		
			601-750		X		

TABLE 3. pH VALUES

14	Very severe caustic	6	
		5	Mild acid
13		4	
12	Severe caustic		
11		3	
		2	Severe acid
10		1	
9	Mild caustic		
8		0	Very severe acid
7	Neutral (distilled water)		

The pH factor is a numerical measurement of the intensity of severity of an acidic or caustic solution. In addition, the degree of concentration of the pump fluid will effect packing selection, and it also must be taken into consideration. From Table 3 you can select the materials which are suited to the pH value of the fluid.

TABLE 4. pH FACTOR DETERMINES CORRECT PACKING MATERIALS

pH range	Applicable packing materials
0-1	TFE Fiber Carbonaceous Fiber Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
2-3	TFE Fiber Carbonaceous Fiber Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
4-5	TFE Fiber Carbonaceous Fiber Aramid TFE-Dispersion Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
6-7	TFE Fiber Carbonaceous Fiber Graphite Tape Cellulostic Aramid TFE-Dispersion Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
8-9	TFE Fiber Carbonaceous Fiber Cellulostic Aramid TFE-Dispersion Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
10-11	TFE Fiber Carbonaceous Fiber Aramid TFE-Dispersion Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon

(continued)

TABLE 4 (continued)

pH range	Applicable packing materials
12-13	TFE Fiber Carbonaceous Fiber Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
14	TFE Fiber Carbonaceous Fiber Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon

TABLE 5. EXPERIMENTAL PREFERENCE RATING CHART

Application data	Service 1	Service 2	Service 3
Motion	Rotary	Rotary	Rotary
Fluid	Clear, neutral	slurry, pH 6-8	Acid slurry, pH 2
Temperature	200°F	200°F	400°F
Shaft speed	800 FPM	800 FPM	2000 FPM
Discharge pressure	50 PSI	50 PSI	150 PSI
Drip rate	100 drops/min	100 drops/min	20 drops/min
Flush	No	Yes	Yes
	Asbestos	Asbestos	Asbestos
Service life	40	40	10
Energy use	10	10	10
Equipment life	5	5	5
	Aramid	Aramid	Aramid
Service life	60	100	10
Energy use	60	60	60
Equipment life	70	70	70
	Graphite/TFE composite	Graphite/TFE composite	Graphite/TFE composite
Service life	90	90	100
Energy use	80	80	80
Equipment life	80	80	80
	Teflon	Teflon	Teflon
Service life	90	90	25
Energy use	90	90	90
Equipment life	60	60	40
	Carbon	Carbon	Carbon
Service life	95	95	95
Energy use	90	90	90
Equipment life	90	90	90
	Graphite	Graphite	Graphite
Service life	100	100	100
Energy use	100	100	100
Equipment life	100	100	100

Note: 100 = Highest efficiency
50 = Satisfactory
30 = Unsatisfactory

TABLE 6. BRAIDED PACKINGS USER COST/LB

The following chart is based on a 1 lb unit of interbraided packing material. The packing cross-section (square) is 3/8".

Material	Cost/lb*
Flax	$ 9.50
Cotton	9.60
Graphited asbestos	13.50
TFE impregnated asbestos	23.00
Aramid	37.50
PTFE	61.00
PTFE/Graphite	69.50
Carbon	111.50
Graphite	170.50

*Cost/lb is based on an average user list price of four major suppliers. Actual cost may vary due to quantity buying or other variable factors.

TABLE 7. BRAIDED PACKINGS COST PER PACKED STUFFING BOX

The following chart is based on packing a pump, valve, mixer or similar rotating shaft driven component. The sealing rings are located in a housing called a stuffing box. Our model for this chart requires five sealing rings per stuffing box. The packing is braided interbraided style, and is 3/8" square cross-section. Costs shown are based in industry norms, and could vary with different suppliers.

Shaft diameter	Graphited asbestos	TFE/Impreg. asbestos	TFE impreg. aramid	TFE/Graphite composite	Graphite impreg. carbon
1"	$2.68	$ 4.29	$ 6.45	$10.50	$12.00
1½"	3.52	5.72	8.60	13.78	16.80
2"	4.65	7.36	11.11	17.72	21.60
2½"	5.64	9.00	13.62	22.31	26.40
3"	6.48	10.43	15.77	25.59	31.20
3½"	7.61	12.57	18.28	29.53	36.00
4"	8.60	13.50	20.43	32.81	39.60

Shaft diameter	TFE impreg. TFE	Graphite impreg. graphite
1"	$13.06	$21.17
1½"	17.42	28.87
2"	22.86	36.57
2½"	27.76	46.20
3"	32.12	53.90
3½"	37.57	61.60
4"	41.92	69.30

TABLE 8. ONE YEAR TYPICAL OPERATING/MAINTENANCE COSTS PACKING A PUMP WITH ASBESTOS BRAIDED PACKINGS VERSUS SYNTHETIC PACKINGS

	Economic factor	Graphited asbestos	Graphite/TFE composite
1.	Expected packing life	4 months	12 months
2.	Packing set costs (1)	$ 13.95	$ 17.72
3.	Labor to repack (2)	90.00	30.00
4.	Sleeve replacement	300.00	00.00
5.	Energy consumption (3)	480.00	384.00
	Total	$883.95	$431.72

Minimum 1 year savings per packed pump by using non-asbestos packing is $452.23.

Other variable cost factors inherent with continued usage of asbestos packings:

1. Downtime costs while repacking glands and/or replacing sleeves.
2. Downtime costs, labor costs, parts costs to replace bearings damaged due to heat build-up caused by high friction and poor heat dissipation qualities of asbestos packings.
3. Product loss necessitated by high drip rates. Also clean up and housekeeping costs.

NOTES: (1) Based on 2" diameter shaft, 3/8" cross-section packing 5 rings per set.

(2) Based on 2 men, 1 hour per repack, $15.00 per man hour.

(3) Based on 2 kw/hr for pump packed with asbestos, 1.6 kw/hr for pump packed with synthetic packing. (Assuming 20 percent differential due to friction, actual differential will be greater), 4000 operating hours per year.

lower friction, and non-abrasiveness of the alternatives, non-asbestos packing should be the first choice of packing users, irrespective of the other problems associated with asbestos usage.

The packings industry has for many years been marketing and recommending asbestos-free packings as the most cost effective seals for all types of rotating equipment. Original equipment manufacturers and maintenance personnel have resisted this movement, mainly for economic reasons. Much time and money has been spent educating these two packing users on the benefits of the asbestos-free alternatives. The major cost then, to the manufacturer of braided packings is not in capital equipment, but in training sales and engineering people to overcome the resistance to changing over to non-asbestos packings because of the lack of understanding of the problems of asbestos usage.

What Effect will the Change-Over to Asbestos-Free Materials Have on the Packings Industry?

The packings industry will be very happy to see the day when there is a total change-over to asbestos-free packings. There are various reasons for this.

First, it is in our, and our customers, best interest to supply the best product for a given application. When asbestos packings were invented and developed, they were the best product then available. Asbestos packings have been used for so long, that they have become the standard. The newer synthetic packings have capabilities which make them much preferable. The resistance to their usage, based on ignorance of the over-all operating costs of utilizing asbestos packings, will eventually be overcome, but it is costing both the manufacturer of packings and the user money, in the meantime.

Second, because the synthetic fibers can be applied in every application, elimination of asbestos as a packing material will allow us to concentrate our resources on fewer products, allowing us to stock a better range of sizes, while at the same time cutting our costs for advertising and training. We will be able to make more efficient usage of our braiding equipment and labor, as we do not have to set-up for asbestos any longer. We will have less expenditures for housekeeping and monitoring equipment to ensure our workers safety.

Finally, we can eliminate the danger of future legal entanglements, and the drain on our resources which accompany such involvement. Any manufacturer that has had any asbestos in any of its products is subject to enjoinment in class action suits, and this has us constantly looking over our shoulder. The sooner that the pump manufacturer, and the pump operator, is forced to go to alternative packings materials the better.

GASKETING

Back in the days of the Roman Empire, a system of aqueducts was constructed to carry water from distant points to the cities. Some sort of material was required to provide a seal between pipe sections since surfaces smooth enough to seal against each other could not be manufactured. The Romans in many instances decided upon flax rope that had been dipped in animal fat, as a very workable solution - and to our knowledge the first recorded instance of gasket use.

Through the years as process temperatures and pressures began to rise, and more reactive fluids came into use, better and better materials had to be found. One of the best turned out to be the combination of long asbestos fibers and high temperature rubbers. Put together with the asbestos serving as the strength member and heat resisting material, and the rubber as the binder and sealing material, gaskets cut from compressed asbestos sheet have found extensive use in virtually every plant in the world.

Even in temperatures well in excess of the char point of the rubber binder, compressed asbestos will still provide a seal. The remains of the rubber and the filler are held in place by the thick matrix of the long asbestos fibers and the axial pressure exerted by a tightly bolted pair of flanges. And at moderate temperatures between a good pair of flanges, pressures in excess of 2500 psi have easily been sealed.

The Asbestos Problem and the Alternatives

Today, with the health hazard of asbestos becoming well known, manufacturers have been hard at work in an attempt to develop gasketing materials that would offer physical and chemical characteristics similar to those of compressed asbestos. Some of the materials currently commercially available are: vegetable fibre, cork composition, cork/rubber, plastics, beater-saturation materials and metal.

Vegetable Fibre Sheet--

Made of plant fibers and a binder, it is mostly used for solvents, fuels, air, gases and refrigerants with temperatures to 250°F.

Cork Composition--

Produced from ground cork granules and protein or synthetic binders; cork is used where light bolt loading is a must (glass and ceramics for example) in water, lubricating oils and petroleum derivatives to 250°F.

Plastics--

Of all the plastics, one has emerged as the most common: PTFE. PTFE can be used in virtually all fluids to 500°F, but in its virgin state can creep (cold flow) under flange loading. Thus PTFE is commonly found loaded with glass or carbon fibers to reduce creep relaxation.

Expanded PTFE--

A micro-porous PTFE structure, expanded PTFE offers high tensile strength, virtually no significant cold flow and extremely high compressibility. Coupled with PTFE's legendary fluid resistance and wide temperature capability (-450°F to 600°F), this material is one of the most significant replacements for compressed asbestos gaskets now on the market.

Rubber--

Both natural and synthetic rubbers are used, with or without a strength member of woven wire or cloth. Normally sheet rubber gasketing is manufactured in a durometer (hardness) from 55 to 80 (Shore A) and varies in thickness from 1/32" to 1/4". See Tables 9, 10, and 11 for the various properties of each rubber.

Graphite--

Manufactured of pure graphite, this material is available with or without wire reinforcement in thicknesses from .030" to .120" and up to 26" x 26" in size. Suitable for use in most fluids to 3000°C.

Beater-Saturation Materials--

Manufactured using a process similar to that of making paper (where the binder is deposited uniformly over the individual fibres while suspended in water), these materials can replace compressed asbestos sheet in most of the same fluids although with temperature limits in the area of 350 to 500°F. (Note: much of the research on asbestos sheet replacements falls into this area.)

Metal--

When very high temperatures and/or pressures are encountered, spiral-wound gaskets are normally specified. Manufactured of continuous vee-shaped metal strip wound radially with a soft high temperature material between each layer, they can be designed for most applications.

The Mechanics of Gasketing

Simply put, a gasket is used to create a static seal between two stationary members of a mechanical assembly confining a liquid or gas under vacuum or pressure. While complex formulas are used to determine gasket design and material selection, a few simple rules can provide the user with enough information to properly select the right gasket most of the time.

Figure 1 illustrates the static forces acting upon a gasket.

In addition to the static forces, 3 other factors affect gasket material selection:

1. Temperature: As temperature increases or decreases, metals expand or contract. This affects bolt loading and can cause softening of the gasket (creep relaxation) or burn-out of the binders.
2. Medium: Highly reactive fluids (acids, caustics, plastics, solvents, etc.) readily attack many binders, thus care must be taken in specifying the correct material with each fluid.
3. General Conditions: The type of flange (see Figure 2), the surface finish (where the surface may range from a rough

TABLE 9. RUBBER PRODUCTS

	New ASTM reference	Features of the more commonly used elastomers in gasketing materials
BUNA-S OR GRS	SBR	Good mechanical properties; economical; extensively seen as the common "red rubber" sheet for gasketing, or as most common binder material in compressed asbestos sheet. Suitable for hot and cold water, air, steam, some mild acids. An all rubber SBR sheet is generally not recommended for oils, solvents nor in aggressive type applications, i.e., ketones, esters, etc.
Neoprene	CR	Excellent oil resistance; low permeability to gases; suited for nonaromatic gasoline and petroleum solvents; highly resistant to ozone, sunlight, weather, aging. Will not propagate flame. Used widely in automotive, aircraft, refrigerant type requirements.
		A more expensive elastomer than SBR. Limited resistance to chlorinated and aromatic solvents such as carbon tetrachloride, benzol, lacquer solvents.
Nitrile or BUNA-N	NBR	Superior to Neoprene in resistance to oils and solvents, aromatic and aliphatic hydrocarbons, animal fats, carbon tetrachloride, lacquer solvents. Has higher temperature resistance than SBR or Neoprene.
		Limited resistance against amines, ketones, esters, ethers and some organic acids.
Natural or Synthetic Natural	NR IR	Primarily employed as gasketing in all rubber sheet form. Properties: exceptional elongation; excellent tear strength; good wear resistance; low permanent set; recovers well; resists most inorganic salts, ammonia, mild acids and alkalies.
		Has poor resistance to oils and solvents and many chemicals and not recommended where exposure to ozone, oxygen or sunlight.
Silicone	SI	Outstanding elastomer for extremely high and low temperatures (-160°F to 400°F); excellent resistance to oxidation, ozone, sunlight, heat aging. Has fair resistance to oil and gasoline but poor resistance to aliphatic and aromatic hydrocarbons. Ordinarily furnished in rubber sheet form only.
Fluorocarbon	CFM FVSI FPM	Excellent resistance to acids, aliphatic and aromatic hydrocarbons, oils, gasoline and many corrosive industrial applications. High temperature limits similar to silicone, but limited in cold applications below - 40°F. Exhibits very low permeability to gases. Ordinarily furnished in rubber sheet form only.

TABLE 10. ELASTOMER COMPARISON CHART[a]

Common or trade name	Chemical designation	Heat resist.	Oil resist.	Ketone/ ester resist.	Ozone resist.	Low temperature resist.	Abrasion resist.	Flame resist.	Gas perm.
Natural	Natural Polyisoprene	5	5	3	5	4	2	5	4
Synthetic Natural	Synthetic Polyisoprene	5	5	3	5	4	2	5	4
Neoprene	Chloroprene	4	3	5	3	4	2	1	2
SBR	Styrene-Butadiene	5	5	3	5	4	3	5	3
NBR (nitrile)	Acrylonitrile Butadiene	4	2	4	4	4	3	5	3
Butyl	Isobutylene Isoprene	3	4	2	2	4	2	5	1
Chlorobutyl	Chloroisobutylene Isoprene	3	4	2	2	4	3	4	1
Butadiene	Polybutadiene Stereo-specific	5	4	3	5	4	2	5	3
Thiokol	Polyalkylenesulfide	4	1	1	2	4	4	5	2
EPR	Ethylene-Propylene	2	5	2	1	3	3	5	3
EPDM	Ethylene-Propylenediene	3	5	2	1	3	2	5	3
Hypalon	Chlorosulfonated Polyethylene	3	2	4	2	4	3	2	1
Silicone	Polydimethylsiloxane	2	5	4	1	1	5	5	5
Urethane	Polyester Urethanes	5	2	3	2	2	1	4	3
Viton	Fluorinated Hydrocarbon	1	2	5	2	5	3	2	2
Acrylics	Polyacrylate	2	3	5	5	5	3	5	3
Hydrin	Epichlorohydrin	3	1	3	1	2	2	4	1

[a] Numerically rated from 1 to 5 indicating comparative suitability for a given property; i.e., "1"-most resistant, "5"-least resistant.

TABLE 11. EFFECTS OF NUCLEAR RADIATION ON RUBBER

	Property effected				
	Tensile strength retention	Resistance to decrease in elongation	Retention of elastic modulus	Retention of dynamic modulus	Resistance to abrasion
NR	3	1 best	1 best	1 best	3
SBR	2	2	2	2	2
NBR	1 best	3	3	3	1 best
CR OR GR	4	4	4	4	4

[a] The numbers in this chart are numerically rated from 1 to 4 indicating comparative suitability for a given priority; i.e., "1" Best.

Note: NR - Natural Rubber
SBR - Styrene Butadiene Rubber
NBR - Nitrile Butadiene Rubber
CR or GR - Chloroprene Rubber

Ref: W.J. Born
B.J. Goodrich

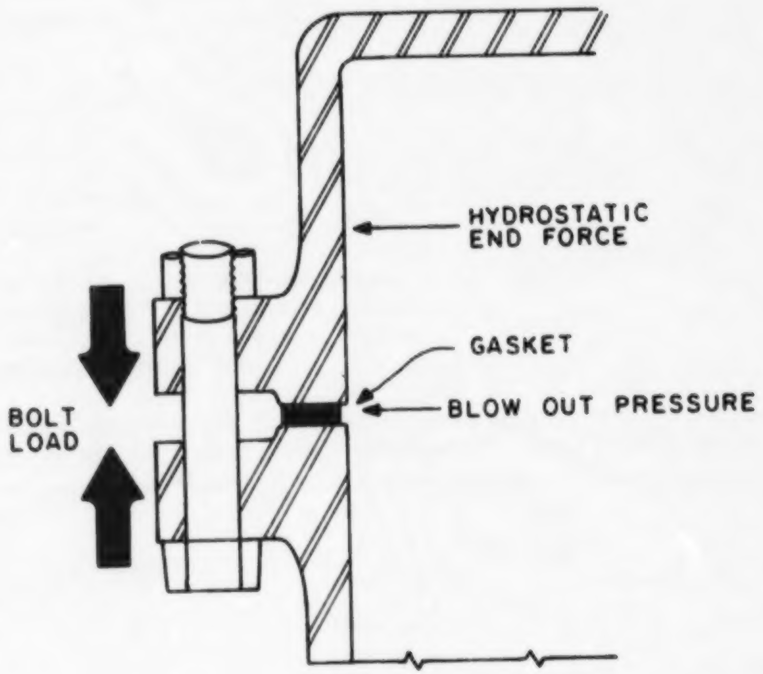

HYDROSTATIC
END FORCE
GASKET
BLOW OUT PRESSURE
BOLT
LOAD

Figure 1. Static forces acting upon a gasket.

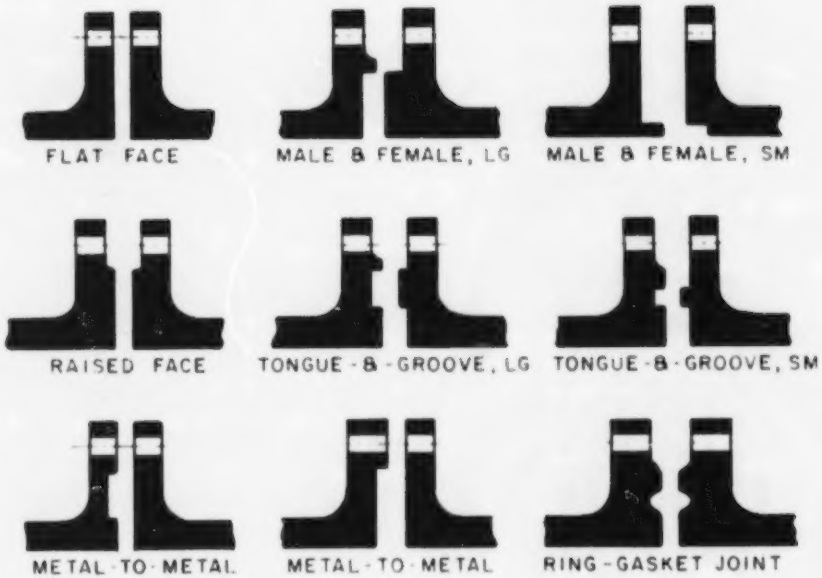
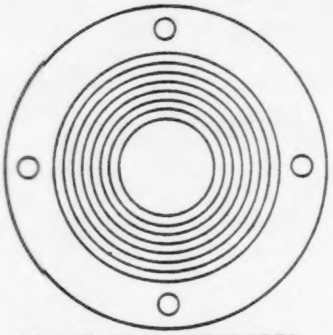

FLAT FACE
MALE & FEMALE, LG
MALE & FEMALE, SM
RAISED FACE
TONGUE-&-GROOVE, LG
TONGUE-&-GROOVE, SM
METAL-TO-METAL
METAL-TO-METAL
RING-GASKET JOINT

Figure 2. Flange facing types.

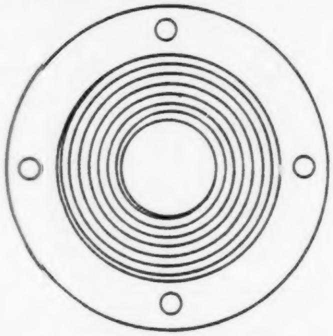
casting to a lapped finish - also see Figure 3) and the number and spacing of the bolts.

As the bolts are tightened, the gasket is compressed and flows into the surface imperfections so that no pathway for leakage remains. Only the surface does the actual sealing. The body of the gasket provides its elastic, resilient properties (density is critical to the flow-through of fluids). As fluid contacts the inner edges of the gasket, in many cases the gasket will swell - increasing its sealing properties; although too much swell signals degradation of the material itself. One final note. The thinner the gasket, the better. But with thin gaskets the better the flange surface finish must be, and the better the finish, the higher the cost of manufacture. Normal gasket thicknesses range from 1/32" to 1/8" with 1/16" being the most popular.

In summation it appears that in the gasketing industry materials do exist that can replace asbestos. It is also apparent that standard sheet materials have been overlooked in many applications. Compressed asbestos sheet gasketing use can be immediately curtailed by applying one of the aforementioned materials. This can be done with little added expense to the customer unless the application is over 500°F. Graphite sheet metal gaskets can replace asbestos over 500°F but their cost will constitute a major expenditure for plant maintenance. It is the 500°F to 1000°F area where gasketing manufacturers are searching for cost effective substitutes.



CONCENTRIC - SERRATED



PHONOGRAPHIC

Figure 3. Types of surface finish.

DISCUSSION ON GASKETS AND PACKINGS

QUESTION (Mr. Castleman): I would like to know if you have some data on the amount of exposure an individual can get, trying to forcibly remove some of these gasket and packing materials?

ANSWER (Mr. Koehler): Green Tweed does not have that particular information. I am sure it is available from OSHA. It is not particularly high. Based on our experience that the amount of fiber coming off of a gasket on a flange, as it is being scraped, probably does not create much of a health hazard. This is because in a wet, saturated area, the fibers are contained. If the binders are burned out and the fibers are fairly loose, it can create somewhat of a hazard. Today, you will find most plants taking extensive precautions with masks and so forth, and roping areas off when they have to deal with that type of problem.

ASBESTOS IN PLASTICS: LOOKING FOR ALTERNATIVES

by

Mr. Matthew Naitove
Plastics Technology Magazine
New York, New York

ABSTRACT

Asbestos has been used as a reinforcing agent in a variety of plastics, most notably phenolic molding compounds, vinyl asbestos floor tile, and polyester autobody putties. In each of these areas, material suppliers and plastic product manufacturers have been looking for alternatives to asbestos, with varying degrees of success. This paper will summarize where asbestos is being used in plastic and what efforts are being made to replace it.

ASBESTOS IN PLASTICS: LOOKING FOR ALTERNATIVES

Asbestos has long been considered from a technical and economic point of view to be a valuable reinforcer/filler for plastics. However, in recent years, the pressure of government health regulations and of a strongly negative public image that has come about with wider recognition of the hazards of using this material have tended to discourage asbestos use in all but a few remaining plastics applications. Given industry's successful efforts to develop cost-effective substitutes for asbestos, as well as recently renewed regulatory initiatives by agencies such as EPA and CPSC, asbestos definitely appears to be on the way out of plastics, though it may take some time before its disappearance is complete.

WHY AND WHERE ASBESTOS HAS BEEN USED IN PLASTICS

The most important functions of asbestos in plastics include enhancement of thermal and mechanical properties, such as heat resistance, stiffness, dimensional stability and impact strength, as well as improving processability through flow control and thixotropy, plus improving economics as a result of resin extension. (Table 1 shows some of the effects of asbestos on physical properties of plastics.)

Because of those desirable properties, asbestos has traditionally been used in a wide variety of plastics resins--including phenolic, vinyl, epoxy, unsaturated polyester, urea, diallyl phthalate, polypropylene, nylon and

TABLE 1. TYPICAL CHANGES IN RESIN PROPERTIES WITH ASBESTOS REINFORCEMENT[a]

	% change				
Material	Flexural modulus	Flexural strength	Tensile strength	Impact notched izod	HDT, °F
ABS	+130	-20	-5	-60	+16
Nylon 6	+170	+100	+85	+20	+200
Phenolic	+120	+50	-	+5	-
Polyethylene	+320	+30	+20	0	+72
Polyphenylene sulfide	+60	+100	+10	+100	+35
Polypropylene	+360	-	-4	+125	+25
Polystyrene	+110	+50	+20	-40	+18

[a] Optimum reinforcement usually requires 20 to 40 percent short fiber asbestos.

Source: "Asbestos" by Robert E. Byrne, Jr., Union Carbide Corp. brochure, reprinted by permission from the Modern Plastics Encyclopedia, McGraw-Hill Inc.

thermoplastic polyester (PBT). Applications have ranged from rocket parts in military/aerospace applications to automotive brake and transmission components, floor tiles, engine housings, bins and containers, and a variety of coatings, adhesives, caulks, sealants and patching compounds.

This paper will concentrate on two areas that have dominated asbestos use in plastics: phenolic molding compounds and vinyl-asbestos floor tile (VAT). In phenolics, asbestos has been all but eliminated over the past eight years; in VAT, the transition away from asbestos appears to be just beginning. Virtually all other asbestos uses in plastics are believed to be extinct, though the picture is somewhat unclear in the area of polyester auto body fillers.

It may be noted that virtually all asbestos use in plastics involves chrysotile asbestos. Some anthophyllite was imported from Finland in the past, but has since become unavailable.

ASBESTOS SUBSTITUTES

Asbestos used in plastics generally costs in the range of 5-40¢/lb. A variety of naturally occurring mineral products in the same price range have proved to be cost-effective asbestos replacements, including mica, clay talc, clay, and wollastonite. Two of these products that are rapidly expanding their roles in plastics filling and reinforcement are mica and wollastonite.

Mica comes in several mineral forms; however, all of them consist of plate-like particles, which can be supplied commercially in a range of sizes and ratios of platelet thickness to diameter.

Wollastonite is a naturally occurring calcium silicate of fibrous or needle-like shape. Typical particle diameter is 3.5 microns and typical aspect ratio (length/diameter) ranges from 3:1 to 20:1. It costs 3-6¢/lb. The primary supplier is NYCO, div. of Processed Minerals Inc., Willsboro, N.Y. The other supplier is R.T. Vanderbilt Co., Inc., Norwalk, Conn. The U.S. Mining Enforcement Safety Administration (MESA) has classified wollastonite as merely a "nuisance dust," and the National Institute for Occupational Safety and Health (NIOSH) has determined that the mineral is neither a fibrogenic nor a carcinogenic substance. Wollastonite reportedly has found use as an asbestos replacement in phenolics, and increasing usage in this area is anticipated.

Besides the above naturally occurring products, a synthetic material of similarly low cost is also gaining acceptance as an asbestos replacement in plastics. It's called Processed Mineral Fiber, or PMF, a product of Jim Walter Resources, Inc., Birmingham, Ala. PMF is a single-strand fibrous material related to mineral wool, which is produced by a patented process from blast-furnace slag. Average fiber diameter is 4-6 microns and average aspect ratio is 40-60. A new grade with an aspect ratio of 150 is in development. According to the supplier, PMF has been accepted as an asbestos replacement in phenolics and epoxy gel coats; mineral-reinforced nylon is said to be another commercial application. (See Tables 2 and 3.)

TABLE 2. PMF VERSUS ASBESTOS IN GENERAL-PURPOSE PHENOLIC[a]

Filler	None	PMF	ST[b] PMF	Asbestos
Wt. %	-	33	33	40[c]
Flex. Str., 10^3 psi	10.4	8.8	12.6	9.1
Flex. Mod., 10^5 psi	6.75	7.98	10.87	10.55
Tens. Str., 10^3 psi	7.52	6.62	8.78	5.01
Tens. Mod., 10^5 psi	4.53	6.01	5.96	4.93
Notched Izod Impact Str., ft-lb/in.	0.18	0.23	0.26	0.25
Volume Resistivity, 10^{11} ohm-cm	1.5	0.7	1.5	0.03
UL94 Flammability (1/8 in.)	V-0	V-0	V-0	V-0

[a] Data supplied by Jim Walter Resources.

[b] Surface-treated.

[c] Commercial compound.

Source: Plastics Technology, September 1977.

TABLE 3. PROPERTIES OF PMF-FILLED POLYMERS[a]

Resin/PMF %	Tens. str., 10^3 psi	Flex. str., 10^3 psi	Flex. mod., 10^5 psi	Notched Izod, ft-lb/in.	Heat-distortion temp., F 66 psi	 264 psi
G-P Phenolic[b]						
0	-	13.1	6.62	0.13	-	-
33	-	9.2	8.23	0.25	-	-
33ST[c]	-	13.4	11.58	0.24	-	-
50	-	8.7	9.38	0.28	-	-
50ST	-	12.4	15.55	0.27	-	-
HIPS[d]						
0	3.9	-	2.97	1.29	181	-
33	4.4	-	7.50	0.58	196	-
50	4.1	-	12.00	0.38	200	-
Acetal[e]						
0	7.6	-	2.80	1.32	308	-
20	6.9	-	5.50	0.55	317	-
33	6.2	-	16.00	0.56	-	278
G-P PP[f]						
0	4.9	-	1.56	0.45	236	-
33	4.5	-	5.50	0.63	266	-
50	4.1	-	8.10	0.69	268	-
PBT[g]						
0 Dry	7.3	9.5	3.30	0.34	-	165
0 Wet[h]	7.0	8.3	2.83	0.46	-	-
33 Dry	7.8	11.8	8.15	0.47	-	359
33 Wet	4.6	8.7	6.45	0.31	-	-
33ST Dry	9.5	14.5	7.84	0.51	-	365
33ST Wet	8.5	13.2	6.02	0.47	-	-
50 Dry	8.2	11.9	12.80	0.57	-	394
50ST Dry	10.8	17.2	12.70	0.53	-	394
Nylon 66[i]						
0 Dry	10.3	11.4	2.04	0.88	-	360
0 Wet	6.9	5.9	1.80	1.85	-	-
33 Dry	9.3	14.7	7.80	0.57	-	394
33 Wet	5.5	8.9	4.30	0.90	-	-
33ST Dry	12.7	17.7	7.30	0.59	-	400
33ST Wet	8.7	11.4	4.30	1.20	-	-
Nylon 612[j]						
0 Dry	8.6	9.4	2.98	0.32	-	217
0 Wet	7.3	6.3	2.12	0.45	-	200
33 Dry	7.3	12.4	6.63	0.41	386	329
33 Wet	6.0	8.7	4.33	0.59	383	324
33ST Dry	10.8	15.0	6.42	0.35	386	322
33ST Wet	9.0	11.2	4.67	0.54	383	328

[a] Avg. aspect ratio of PMF varies from 40 to 60 for the different polymers tested, though this reportedly affects the data little.

[b] Durez 12763.

[c] Surface treated.

[d] Shell-324.

[e] Celanese M-90.

[f] Shell P-520.

[g] Celanese J-105.

[h] Water conditioning: 16-hr soak of molded specimen at 122 F.

[i] DuPont Zytel 101.

[j] DuPont Zytel 151 L.

Source: Plastics Technology, April 1977.

Still another synthetic product which has become important for asbestos is glass fiber. It is being used in some new asbestos-free phenolics (see below), and development of new sizes and types of glass fiber are expected to increase its utility in this area, according to one phenolic supplier. One potential drawback to glass fiber, however, is that it can significantly increase the cost of a plastic compound relative to asbestos, though this need not always be the case. Although glass fiber is available in many forms, some typical grades used in plastics are priced in the range of 60-70¢/lb.

One more potential asbestos replacement is presently still in the experimental stages. Franklin Fiber is a crystalline calcium sulfate microfiber with a diameter of 4-6 microns and aspect ratio around 100:1. It's produced in pilot-plant quantities by CertainTeed Products Corporation, Elverson, PA., and costs 10-15¢/lb. The product is slightly water soluble, and company sources say that it is made from a non-hazardous material and does not tend to remain in the body if ingested.

It should be noted that a considerable amount of research is being devoted to increasing the utility of asbestos-replacement products in plastics by treating them with silanes or other coupling agents that promote a chemical bond between the filler and the plastic matrix. Use of such surface treatments tends to improve both the processability and ultimate mechanical properties of filled and reinforced compounds.

Because of the above developments, asbestos' future in plastics is in doubt. Table 4 shows projections for total asbestos use in plastics, one set of figures dating from 1974 and one set prepared in 1980. In 1974, the average growth rate projected was 9%/yr; in fact, it has turned out to be more like 7%. For the future, the latest projection is for 4.5%/yr growth, though even this is termed "optimistic" by the source of these figures. The remaining plastics market for asbestos is VAT, whose market curve reportedly appears flat in the future, and will probably decline as asbestos substitutes are found (see below).

REPLACING ASBESTOS IN PHENOLICS

About six years ago, according to one major phenolic producer, approximately 70% of all molded phenolic parts contained from 1% to 30% by weight asbestos. At one time, 250-million lb of phenolic compounds reportedly contained asbestos; today, that figure is said to be 50-million lb out of a total market of 300-million lb.

Asbestos-filled phenolics have been used in a number of applications where heat resistance is required, including automobile brake and transmission components, electrical parts, pot handles, and various knobs and other components of large and small appliances, such as clothes washers and dryers, dishwashers, refrigerators, portable heaters, popcorn poppers and broilers.

TABLE 4. ASBESTOS USAGE IN PLASTICS

1974 Market analysis (million lb)					
1971	1973	1974	1976	1984	Avg. annual increase '74-'84
350	405	441	523	1042	9%

1980 Market analysis (million lb)				
1976	1980	1985	1990	Avg. annual increase '80-'90
440	518	645	803	4.5%

Source: Business Communications Co., Stamford, Connecticut.

In 1972, General Electric Company's Plastics Division was the first major phenolic compound supplier to announce that it was completely eliminating all use of asbestos. In 1976, another major, Durez Division of Hooker Chemicals & Plastics Corporation said it would do the same. The company finally completed the transition in 1979. Fiberite Corporation, which was at one time a small factor in asbestos-filled phenolics, also eliminated asbestos use several years ago.

Only recently has it become apparent that all remaining producers of phenolic molding compounds intend to pursue a thorough phase-out of asbestos, which they hope to accomplish by the end of 1980. Rogers Corporation, Reichhold Chemicals, Plastics Engineering Company, and Valite Division of Valentine Sugars, Inc. all now intend to discontinue using asbestos-filled grades. Only one smaller producer, Resinoid Engineering Corporation has said that it has no plans at the moment to drop asbestos; rather, the company appears to be taking a "wait-and-see" attitude regarding new proposed government regulations. In addition, a very minor amount of asbestos-filled phenolic is being imported from Canada.

It has taken phenolic suppliers several years of continuous evolutionary development to arrive at a full line of asbestos replacement. At first, there was considerable customer resistance to the new products while asbestos grades were still available, but this customer resistance seems to have been largely overcome. To quote a spokesman for one major phenolic supplier; "It was a product-by-product change, using a variety of materials to develop the same processability and end-product properties as those provided by asbestos. The transition was difficult. At one time, 90 percent of our phenolic compounds contained some asbestos--today we haven't got a pound on the premises."

Although non-asbestos formulations are proprietary, and probably contain mixtures of fillers, products such as clay, talc, wollastonite, glass fiber and Processed Mineral Fiber are all said to have been used as asbestos replacements. Mica has also been evaluated in this application, but with limited success. Although mica reportedly builds stiffness much more than equivalent loadings of asbestos, experiments reportedly showed that mica-filled phenolics cannot be exposed to elevated temperatures for long periods without blister formation, according to sources at a mica producer, Marietta Resources International. However, this company reports that better property retention is exhibited for phenolic samples containing finer grades of mica.

Today, it appears that some, if not yet all, phenolic suppliers have been able to replace asbestos across the board with phenolic compounds that exhibit nearly identical properties (90-98% as good, according to one supplier) at nearly identical cost. (See Table 5.) In some cases, electrical properties and surface appearance are said to have been improved by replacing asbestos. There are also reports that some asbestos-free phenolic compounds flow better for easier processing.

But there are also some trade-offs, however. In flame resistance, an asbestos-filled grade can receive an Underwriters Laboratories UL 94V-0 rating at 0.040 in. thickness, while a non-asbestos grade may have to be 0.060 in. thick to obtain the same flammability rating. To quote a major phenolic supplier, "We've pretty much closed our books on asbestos. We've survived the transition in good fashion, but in our replacement products we have sacrificed long-term heat resistance to some degree." There seems to be some difference of opinion in industry as to whether asbestos-free phenolics do or do not provide the same degree of long-term heat resistance. Some suppliers say the heat resistance (retention of properties at elevated temperature) of newer asbestos-free grades is more than adequate. But for the very highest performance materials, confidence in asbestos replacements may still be less than absolute.

Also, it should be noted that replacement of short-fiber asbestos has proved easier than finding substitutes for long-fiber asbestos, which is used in phenolics for high impact strength. Long glass fibers reportedly can provide the same degree of impact stength, but may cost as much as 40% more than long asbestos fibers. Long glass may also have the disadvantage for the user in creating more machine wear than does asbestos.

ASBESTOS IN VINYL FLOOR TILE

One asbestos supplier estimates that, at one time, as much as 200-million pounds of asbestos was used in vinyl-asbestos floor tile. This source estimates that the figure may be slightly less now, owing to competition with VAT from synthetic carpeting materials and non-asbestos containing types of vinyl flooring. VAT generally contains only 10-15% by weight of asbestos. A very short-fiber asbestos is used, costing about 5¢/lb.

TABLE 5. GLASS FIBER VERSUS ASBESTOS IN PHENOLICS

Grade	RX862	RX865	RX866D	RX867	RX867D	RX462	RX466	RX468
Filler	Glass	Glass	Glass	Glass	Glass	Asbestos	Asbestos	Asbestos
Specific Gravity	1.88	1.88	1.94	1.71	1.78	1.79	1.70	1.72
Tensile Strength, psi	6,500	7,500	6,000	6,000	6,000	6,000	6,500	6,000
Flexural Strength, psi[a]	12,000/ 14,000	15,000/ 17,000	11,500	11,500	11,500	12,000	11,000	10,000
Flexural Modulus, million psi	2.3	2.5	2.5	1.8	2.0	2.0	1.8	1.8
Compressive Strength, psi	28,000	33,000	28,000	27,000	28,000	24,000	30,000	26,000
Deflection Temperature,[b] °F	500+/ 550	550+/ 550+	550+/ 550+	450+/ 500+	500+/ 550+	500+	500+	450
Dielectric Strength, V/mil Short Time	300	300	290	230		125	150	150
Step by Step	250	250	220	180		100	100	100

[a] Compression molded/transfer molded.

[b] As molded/post baked.

Source: Rogers Corp., Rogers, Connecticut.

Recent conversations with two VAT producers (some refused to discuss the subject) indicated that both are working actively to either replace asbestos with something else or perhaps to develop a new flooring product based on an entirely different plastic that does not require filler. Also, one producer said it had been able to sharply reduce the asbestos content in some of its current products, but would not explain how.

One of the two VAT producers interviewed said it hopes to be able to phase out asbestos in the next two years, the main reason for doing so being the bad name asbestos has acquired--consumers are becoming afraid of it anywhere. According to this supplier, all VAT producers are working to eliminate asbestos. "Asbestos is dead," he said.

ASBESTOS IN OTHER PLASTIC PRODUCTS

Numerous miscellaneous uses of asbestos in plastics have appeared over the years, and some were once thought to be quite promising growth areas, but all are thought to be defunct today. These include nylon and polypropylene auto and appliance parts (asbestos has since been replaced by glass fiber, mica and talc), vinyl plastisol coatings and sealants, epoxy coatings and roofing compounds, and polyester premixes for molding auto and tractor parts, engine housings and bins and containers. In one application where asbestos has been used, polyester auto body putties, it's not entirely clear whether it may still be used to any extent. Spokesmen for the Autobody Filler Manufacturers Association (AFMA), headquartered in Chicago, assert that its member companies do not use asbestos but also say that some non-affiliated firms may do so. Platy talc is the approved filler, says AFMA. At least some sources in that industry believe that there is use of asbestos or asbestos-like materials (perhaps as a contaminant in some talcs) in some body putties, but this could not be confirmed directly.

ACKNOWLEDGMENT

I would like to thank my associate, Assistant Editor Carl Kirkland, for his invaluable assistance in researching this topic.

DISCUSSION ON PLASTICS AND FLOORING

QUESTION (Mr. Koehler): For my own edification, I'd like to know if all plastic products that are put out for consumer use today contain warning labels?

ANSWER (Mr. Naitove): I am not aware of any consumer product made of plastic containing asbestos that has a warning label. I don't believe such a thing exists.

ANSWER (Chairman Guimond): I have seen a few manufacturers put identifiers on tile and a few other products, but that is all.

SINGLE-PLY ROOFING AS A SUBSTITUTE FOR ASBESTOS ROOFING FELT

by

Mr. David E. Bailie
Koppers Company, Inc.
Pittsburgh, Pennsylvania

ABSTRACT

Asbestos has served industry and consumers in many ways. In the roofing industry, it has solved a problem and created another. The rapid changes now taking place in the roofing industry have presented adequate alternatives to the use of asbestos-containing roofing felt.

Asbestos has served industry and consumers in many ways. In the roofing industry it has solved a problem and created another.

Some of you may not be familiar with the construction of a built-up roof, so I would like to give you a quick course on how a roof is usually constructed.

A typical built-up roof is constructed by alternating layers of bitumen and felt; the bitumen being either asphalt or coal tar, and the felt being organic, asbestos, or most recently, glass.

Organic felt is in greater use, and at one time, was produced with a high rag content. However, economics and lack of supply has caused the producers of organic felt to go to a high paper content with a small amount of wood fiber. Dry felt is run through a saturator that allows the dry felt to soak up the bitumen saturant close to a point of saturation.

The bitumen used in built-up roofing is either asphalt or coal tar. Asphalt is a derivative of petroleum and is available with various softening points to suit the specific needs of the roofing contractor. Coal tar is derived by the destructive distillation of coal, better understood as the production of coke used for making steel. Both bitumens require heat to cause the bitumen to be fluid.

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After the roof deck is in place, insulation is attached to the deck by means of mechanical fasteners or a hot adhesive. The emphasis placed on conserving energy has increased the use of insulation and many times two layers of insulation are applied. The felt laying begins by mopping on a prescribed amount of bitumen into which the felt is embedded. The application progresses from one side of the roof to the other, laying the felt in shingle-like fashion. When a gravel surface is required, a flood coat of bitumen is poured on the top felt and gravel is embedded while the bitumen is still hot.

Built-up roofing is very labor intensive. Modern practice utilizes mechanical equipment to speed installation. Mechanical insulation fasteners are driven into the insulation and deck by a drill-like device. The bitumen is laid down with a spreader instead of a hand mop, and the felt is rolled in behind it. On some jobs, the felt is contained on the same piece of equipment. The top pour of bitumen is also laid down with this piece of equipment, and when gravel is required, a gravel buggy is used to lay the gravel.

The success and longevity of the roof is dependent upon the homogeneous formation of the layered construction, and you should now understand why this type of roofing is called built-up roofing.

A built-up roof is analogous to plywood in that the layers of a roof have little strength individually. A number 15 organic felt, for example, has average breaking strength of 30 lbs. in its longitudinal direction and 15 lbs. in the transverse direction, and can easily be torn. When the felts are laminated with bitumen, however, the strength is substantially increased. The strength of a built-up roof is important because of the stress induced by structural movement and temperature fluctuations.

The degradation or weathering of a organic felt occurs when it becomes exposed to the atmosphere. The absorption and subsequent drying of the organic felt causes it to break down and eventually blow away. The ability of organic felts to absorb moisture creates other problems for a roof. It was these problems that opened the door for the use of asbestos felts in the roofing industry.

Asbestos roofing felt became the new kid on the block. A better roofing felt. One that did not absorb water and rot away. A roofing felt that had better fire resistance. Indeed, a premium roofing felt to produce a premium roof. And, I might add, at a premium price. Currently, asbestos felt is priced at approximately twice the price of organic felt.

Asbestos felt entered the roofing industry as a substitute for organic felt primarily for roofs that had a smooth surface, that is, without gravel on the surface. Asbestos offered a distinct advantage on a smooth surface roof because this type of roof was more susceptable to degradation, and asbestos felt would not deteriorate as would an organic felt when the top coating of asphalt weathered and allowed moisture to penetrate. The use of asbestos felt spread to other roofing applications as the advantages of asbestos felt were broadcast. There is a single law that applies to everything in existence -- Murphy's Law. As it sometimes occurs with products that offer advantages, there are disadvantages as well. Sometimes the disadvantages do not appear until late in the game. Such was the case with asbestos felt. Along with the high price of asbestos felts, we have found that asbestos felts are lacking in breaking strength. When tested as per the same ASTM (American Society for Testing and Materials) method used to test organic felt, asbestos possesses 1/3 less breaking strength than that of organic felt. Consequently, the industry has experienced a higher rate of splitting roofs when asbestos felts were used to build up the roof.

The use of asbestos felt for roofing has greatly diminished. There are only two producers of such felt in the U.S. There are viable alternatives. One such alternative is glass felts. The other is a single-ply roofing system.

Although there have been single-ply systems existing in this country for 15-20 years, they did not blossom until the early seventies. At the present time, the market is flooded with various single-ply systems. However, all of them can be categorized into two groups - modified bitumen or polymeric systems. Within those two groups lies a real variety.

Modified bitumens include systems in which the bitumen has been modified in different ways. Some are reinforced, others are not. Some are adhered with hot adhesive, others with a cold adhesive. And there are systems that are not adhered at all, but instead are held down with heavy ballast.

The polymeric systems have similarities to the modified bitumen systems in that they contain different polymers. Also, some are reinforced while others are not. In addition, polymeric systems can also be loose-laid or adhered. Polymeric systems include EPDM (Ethylene Propylene Diene Monomer), Butyl, Neoprene, PVC (Polyvinylchloride), CPE (Chlorosulfonated Polyethylene), and PIB (Polyisobutylene).

There simply is not enough time to delve into the makeup of each membrane, nor am I qualified to adequately describe the composition of each. Each system also has its own procedure for application, and I'll not bore you with that either.

Instead, I would like to dwell on the two generic methods of application. Loose-laid and adhered or semi-adhered.

Adhered systems are those that are held down with an adhesive. All polymeric membranes use a cold adhesive, while some modified bitumen membranes will use hot, and others use cold adhesive. The application of adhesive is achieved simply by rolling, spraying, brushing, or mopping the adhesive onto the surface to which the membrane is to be applied. The membrane is then laid in place, overlapping the preceding layer. The laps are then sealed to provide a watertight system.

The semi-adhered systems are applied by first mechanically attaching a small piece of the membrane (9-12" square). Adhesive is then applied to these patches which have been placed 1'-2' apart. The membrane is then placed so that the membrane is adhered only to the patches. The membrane is sealed at the laps in the same manner as the adhered systems.

The loose-laid systems are a new concept in the roofing industry. In my opinion, it makes a great deal of sense. This method of application places the membrane on the deck, insulation, or existing roof loosely, without any attachment. The laps are sealed in the usual manner and heavy stone is placed on top of the membrane to resist wind uplift. The value of this system is that the substrate can move underneath without transmitting stress to the roofing membrane.

In summary, I've given you a quick course in the construction of a built-up roof, its components, the entry of asbestos felts, and an alternate to the use of asbestos roofing felts.

In closing, I want to add that knowledgable people in the roofing industry feel that the demise of asbestos roofing felts is imminent and asbestos felts can, at the present, be substituted with materials of proven performance with no economic disadvantage.

ROOFING FELT

by

Ms. Nancy Roy
GCA Corporation
Bedford, Massachusetts

ABSTRACT

Asbestos provides dimensional stability, rot resistance, fire resistance, and heat resistance to roofing felt that is impregnated with asphalt. Commercially available substitutes include organic and fiberglass felts. Alternative products are compared on the basis of composition, strength, durability, product life, cost, and length of time in the marketplace. Substitutes for asphalt-saturated asbestos roofing felt are well-established in the roofing industry. Installed costs of asphalt-saturated roofing felts are surprisingly close. Labor costs for installation outweigh the costs of materials by a significant factor.

INTRODUCTION

The following subjects: roofing felts and nonasbestos substitute products including organic and fiberglass felts, their composition, special qualities, cost differentials, and length of time on the market will be discussed in this paper. From this information, conclusions may be drawn as to the availability and economic reality of alternatives to asbestos roofing felt.

Roofing has been a basic need ever since man first built crude shelters to protect himself from the weather. In the past, settlers used sod and thatched roofs as these materials were cheap and easy to come by, but they needed to be replaced at frequent intervals, and often leaked in heavy rain storms.[1] At present, home and business owners are offered a wide variety of roofing materials from which to choose, all of which fit various requirements and contribute desired attributes to satisfy varied roofing needs.

A basic distinction can be made between roofs belonging mainly to homeowners and large roofs on business properties. Roofers would view the difference in terms of "minimum slope" for which a roof is adapted. Whereas the majority of homeowners' roofs are quite sloped, commercial and industrial roofs are mainly flat. Asbestos felt underlay may be used in both instances, but the industrial or built-up roofs are described here.

In all cases, the material discussed is used as an underlay either to other common residential roofing systems such as asphalt shingles or classic cedar shakes where asbestos helps prevent moisture penetration, or to asbestos felt layers themselves in industrial built-up roofing.

ASBESTOS ROOFING FELTS

Asbestos fibers are useful in roofing felts because they provide:

- dimensional stability, and
- resistance to rot, fire, and heat.

Dimensional stability is particularly important. Given the extreme weather conditions a roof must face, such as rapid heating and cooling of the roof surface, cracking may occur which allows water penetration, particularly in damper climates or in areas where snow accumulates on the roof and is then subject to periodic melting. Asbestos roofing is considered by many roofers to have an exceedingly long life.[3,4] Rot resistance is of paramount importance on flat or nearly flat roofs with poor drainage. The fine resistance of asbestos felt provides an extra margin of safety to property owners, and thermal resistance enhances roof durability.

Asbestos felt sheet is manufactured with varying formulations on conventional paper-making machines, then converted into roofing felt by saturation with asphalt or coal tar. Major United States companies who have produced asbestos roofing felt include: Johns-Manville Corporation and Celotex Corporation. Manufacturers often make the felted sheet at a centrally located site and ship this product to geographically scattered sites for saturation. This saves on shipping costs as the unsaturated felt weighs less[5]. Asbestos roofing felt is typically composed of 85 to 87 percent asbestos fibers, 8 to 12 percent cellulose fibers, and 3 to 5 percent starch binders[6]. Grade 6 or 7 chrysotile fiber imported from Canada is usually used. Other materials, such as wet and dry strength polymers, Kraft fibers, fibrous glass, and mineral wool are often added as fillers. The paper is made in either single or multilayered grades and may have fiberglass filaments or wire strands embedded between paper layers for reinforcement. The felt's thickness or grade and the amount of asphalt costing required depend upon the product's intended use.

In built-up roofing systems, the most common type - a hot roof - often involves the use of asbestos roofing felt. Cold roofs, not requiring the application of hot tar or asphalt, were covered in the discussion of single-ply membrane systems; only hot roofing systems will be considered here. They involve the application of several plys or layers of roofing felt alternating with asphalt or tar, often with a top layer of gravel imbedded in the asphalt. Layers used may consist of organic, fiberglass, or asbestos felts.

Built-up roofing such as this is commonly prepared at the job site by cutting lengths from product rolls to the required sizes and shapes. "Built-up", as implied, refers to the practice of layering or building up paper lengths on top of each other while hot roofing tar is mopped between the layers for adhesion and/or additional weather protection, having a sandwich effect. The roofing is attached to the surface roof deck with adhesive tars (which may also contain asbestos) or by nailing if the roof can accept such treatment. Built-up roofs can be topped with:

- gravel
- smooth, or
- mineral surfaces.[7]

Gravel and smooth roof tops are similiarly constructed except that smooth-surface roofs are only lightly mopped with asphalt whereas gravel surfaces are flooded with asphalt and then covered with aggregrate gravel which generally serves more for appearance and ballast than for true protection. In mineral surface roofs, roofing paper is sealed with weather grade asphalt embedded with opaque, noncombustible mineral granules giving the builder a choice of roof colors. Asbestos roofing felt has an advantage over organic felt here as it does not require a gravel surface, a feature which makes it easier to inspect and repair.[8]

Asbestos felt may also be used as an underlayer for other roofing products, mostly in residential applications. For this, asbestos roofing paper is attached to the roof deck, again by tar adhesives or by nailing, then covered with shingles, cement sheets, or other forms of common roofing. Included in this category are: metal roofs, which formerly were often galvanized steel in corrugated sheets but now are mostly non-rusting aluminum panels; slate roofs, an old stand-by which is now offered in imitation form offering the hand-cut slate look at a lower cost; and tile roofs and wood shakes, both commonly seen materials used mainly for homeowner applications.[1] At least 60 percent of asbestos roofing felt is applied during re-roofing jobs while the remainder is used in new construction.[9]

ALTERNATIVE ROOFING FELTS

There are two alternatives to asbestos roofing felt other than singly-ply membrane systems. These substitute products are organic felt and fiberglass felt.

Organic felts have been used in United States built-up roofing systems for about 25 years. They are made primarily from cellulosic fibers on paper-making machines, and, as with all roofing felts, are saturated with coal tar or asphalt. Major manufacturers of organic felts include: Johns-Manville, Celotex, Bird and Son, Koppers Company, GAF, and CertainTeed Corporation.

Fiberglass roofing is a newer product, introduced around 1964 by Owens-Corning, but only recently enjoying widespread use. It is composed of glass or refractory silicate and a binder. Owens-Corning, Johns-Manville, and others produce fiberglass felt; other companies such as PPG Industries and Reichold Chemical Company manufacture the basic fiberglass strand and sell this to the actual paper product manufacturers.[10, 11]. Three basic manufacturing processes are employed, including the continuous filament process used by Owens-Corning, a steam blown process using shorter fibers, and a slurry process similar to the basic paper-making process.[2]

To compare these two products with asbestos felts, several factors must be considered, including:

- strength and durability
- product life
- product cost, and
- length of time that the product has been available.

Although organic felt rates lowest in terms of strength and durability, it is still the most widely used. The primary reasons are its low cost and time-tested nature; since it has been on the market the longest, its qualities are well known. Fiberglass products have been praised for exceptional uniformity and natural venting characteristics. More uniform porosity of this product allows deep penetration of asphalt leading to improved interply adhesion.

Fiberglass has the same technical features as asbestos, but requires less asphalt saturation. Both fiberglass and asbestos systems are inorganic and, therefore, have better rot resistance and dimensional stability than organic systems.[8]

ECONOMICS

A comparison of installed unit costs, which may be more meaningful, still shows organic felt to be least expensive, but the prices are now closer. Organic felt averages about $60.00 per installed square, asbestos and fiberglass around $70.00, and single-ply membrane at about $100.00. This is where the single-ply membrane really shows itself to be more competitive than apparent based only on material cost, because it is not labor intensive and material savings (such as tar or asphalt) become evident. This should make products like fiberglass and single-ply membrane systems become even more competitive in the future. Industry sources believe that these materials will reduce the share of both organic and asbestos felts in the built-up roofing market.[8]

Lifecycle costs should also be considered: that is to say, an asbestos roof may be slightly more expensive than an organic roof, but if the asbestos roof is replaced every 20 years while the organic roof must be replaced every 10 years, the asbestos roof is more economical. Unfortunately, data on the expected lifetime of the different roofing types is sparce. Lifetimes depend on such factors as surface finish (smooth is more susceptible to degradation) and whether coal tar or asphalt is used (coal tar lasts longer), as well as climate and yearly weather cycles; the roof lifetime is a difficult parameter to predict.[12]

A product such as Johns-Manville's Glas Ply system meets the 200 pounds per square inch (at 0°Fahrenheit) tensile strength preliminary performance criteria recommended by the National Bureau of Standards. This product requires less mopping asphalt than other systems as more asphalt is impregnated during product manufacture.

Cost is certainly a most important aspect of substitute analysis. Specific roofing costs are given in Table 1, attached. Two cost comparisons are valuable: first, basic roofing material costs for asbestos, organic and fiberglass felts and second, the cost for installed units of roof. Since rolls come in different sizes and the number of layers installed on the roof will vary depending on the felt used, the basic unit of comparison employed is the square - a one hundred square foot area of roofing.

In terms of material cost per completed square, only organic felt is cheaper than asbestos, while asbestos and fiberglass are nearly equal. In general, prices range from around $10.00 a roll for organic, to about $25.00 per roll for asbestos and fiberglass, and finally to about $65.00 for the single ply membrane system. Prices differ from the conference hand-out figures, in that, in most cases, they are now lower. Only the cost of asbestos has gone up. Asbestos and fiberglass are nearly equal in quality and durability, and cost, which is very close at present, will probably shift to favoring fiberglass in the near future.

Since a price comparison of average costs of installed roofs only shows about a $25 fluctuation between products, one must also look at other attributes. Time-tested qualities and builder experience together with these cost findings now become valuable in predicting market trends.

CONCLUSION

Organic felts have been marketed longer than all other roofing materials covered, although the single-ply membrane system has been used in Europe for a longer period than its 5-6 year introduction in the United States. Asbestos felt is also a fairly new product in the roofing industry; however it had an advantage that shot production ahead. In 1968, the American Society for Testing and Materials issued a recommendation for the use of asbestos felt on built-up roofs which helped asbestos felts quickly penetrate the roofing market. Now, competition and health concerns appear to be dulling this edge. In 1976 built-up roofing sales of all types were about 53 million squares. Organic systems had about 45 percent of the market, asbestos felt 25 percent, and fiberglass felt 10-15 percent.[8] The remainder consisted of single ply and other roofing systems. Some companies such as GAF and Nicolet Industries, have terminated or cut back their production of asbestos roofing felt. From telephone surveys it appears that the use of organic felt is widespread, at least in the Northeastern United States. In the West and Soutwest tile roofs are common.

A product such as tile roofing, however, is suitable only for pitched roof surfaces which are usually residential, as compared to built-up roofs where asbestos is used. Tile roofs require little underlay, which likely increases their popularity.

Since only organic felt roofs have been used in the United States for more than 20 years, it is difficult to draw firm conclusions concerning the long-term durability of the various roofing systems. Industry representatives differ in opinions of superiority between asbestos, fiberglass, and organic felts, with questions stemming from possible variability in fiberglass felt quality. Conversion of asbestos felt manufacturing lines to the fiberglass felt mat product requires manufacturing experience and applicator training. Nevertheless, fiberglass seems to be quickly gaining on the built-up roofing market. Problems with alternative materials such as these are currently being investigated by manufacturers; many difficulties will be minimized when installers become more familiar with their use. If costs become more competitive, as they seem bound to be with rising asbestos and petroleum product costs, there is every reason to believe that dependable, cost-competive substitutes are available to replace asbestos roofing felts.

TABLE 1. ROOFING COSTS*[3,4,13-16]

Roofing felt type	Retail cost per roll ($)	Installed cost per square ($)
Organic felt	10.00	$50-60
Asbestos felt	25.00	$70
Fiberglass felt	25.00	$70
Single-ply membrane system	65.00	$100

*Cost includes labor and materials for base sheet plus equal amounts of layers of felt.

Source: Telecon. D. Bailie, Koppers Company, with N. Roy, GCA Corp./Technology Div. July 11, 1980.

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14. Telecon. G. Perkins, R-625 Products Marketing Manager, Owens-Corning Company, Toledo, OH, with D. Ramsay, GCA Corp./Technology Div., August 29, 1979.

15. Telecon. Salesman, Bradco Supply Corporation, Woburn, MA, with D. Ramsay, GCA Corp./Technology Division, August 17, 1979.

16. Telecon. D. Bailie, Koppers Company, Pittsburg, PA, with N. Roy, GCA Corp./Technology Div., July 9, 1980.

DISCUSSION ON ROOFING PRODUCTS

QUESTION (Mr. Shaimes): Do you use the same number of plys for a glass fiber. inlay as you use for organic fiber inlay?

ANSWER (Mr. Bailie): Right now, I think the industry is trying to reduce the number of plys of felt used. You will find each producer with his own various specifications. Most of the time, you will find the same number of plys. I would not be surprised, in the future, as the production of glass felts is firmed up, that the number will be reduced; but as a rule, right now, I think it is most typical to find the same number of plys. The use of a glass base sheet, a very heavy glass, might become more prominent, thereby allowing the number of plys to be reduced even further.

QUESTION (Mr. Castleman): A couple of questions. One, do you have any problems of irritation or skin reactions from workers handling the fiber glass products; and, two, can you tell me the size distribution and diameter of the fibers used in the fiber glass product?

ANSWER (Chairman Guimond): I think the size question, relative to the fiber glass product, will be discussed in the health-related session. I personally do not know which size fibers are used.

ANSWER (Mr. Bailie): They will vary by different processing methods.

Certainly, when you handle fiber glass in its raw form, it can be irritative. However, in fiber glass felts, the felt pretty well encapsulates the glass fiber, so unless you happen to hit the edge of the felt where it has been cut, you should have no irritation at all. There is enough asphalt on it to protect you from the glass fiber itself.

QUESTION (Dr. Millette): I am with the EPA Water Health Effects. I want to make one comment about some work that we are doing on the exposure of asbestos to home cisterns from different types of roofing material.

We have not done a lot of work yet, but in one case we looked at asbestos cement tiles and found that over a number of years, the tiles had deteriorated by the weather. Therefore a roof that collected water for a cistern would contain very high amounts of asbestos. When we looked at several fairly old roofs that used the asbestos roofing felt material, we did not find any fibers in the drinking water of the cisterns that collected water from these types of roofs. But we did take samples of the roof and dissolved it and did find that fibers were present. But, apparently they are well enough encapsulated that they did not come off in large numbers into the drinking water. The third type of roof was asbestos-containing coatings painted onto metal roofs. At least in one case we have found some asbestos fibers in the drinking water in that cistern.

You gave a breakdown on the amount of different materials sold in the last year or so. Do you have an estimate on how many residential roofs in the United States would have asbestos felt materials in them?

ANSWER (Mr. Bailie): I seriously question whether any have asbestos felts on them because it is quite unlikely that a roofing contractor would use an asbestos asphalt saturated felt underneath shingles when he can use an organic felt.

MILL APPLIED COATINGS FOR UNDERGROUND PIPELINES

by

Mr. Jack Wink
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ABSTRACT

The purpose of this discussion is to cover the fundamental philosophy for the selection, application and performance of pipe coatings, as used for prevention of the deterioration of metals buried in earth or submerged in water.

The basic function of a pipe coating on underground or underwater structures is to isolate the metal from contact with the surrounding environment. Metals are unstable in these environments and reversion from their commercially pure, unstable form to a more stable chemical compound is corrosion. Pipe coatings form the first line of defense against this corrosion. Since a properly selected and properly applied coating should provide approximately 99 percent of the protection required, it is of utmost importance to know the advantages and disadvantages of all available coatings. "The right coating materials properly used will make all other aspects of corrosion control relatively easy."[1] This coating system will be supplemented with cathodic protection to give the necessary overall corrosion control. Today with the many coating systems available, the job of selecting the proper coating necessitates careful analysis of the many desired properties for an effective pipe coating.

PIPE COATING FUNDAMENTALS

The purpose of this discussion is to cover the fundamental philosophy for the selection, application and performance of pipe coatings, as used for prevention of the deterioration of metals buried in earth or submerged in water.

The basic function of a pipe coating on underground or underwater structures is to isolate the metal from contact with the surrounding environment. Metals are unstable in these environments and reversion from their commercially pure, unstable form to a more stable chemical compound is corrosion. Pipe coatings form the first line of defense against this corrosion. Since a properly selected and properly applied coating should provide approximately 99 percent of the protection required, it is of utmost importance to know the advantages and disadvantages of all available coatings. "The right coating material properly used will make all other aspects of corrosion control relatively easy.[1]" This coating system will be supplemented with cathodic protection to give the necessary overall corrosion control. Today with the many coating systems available, the job of selecting the proper coating necessitates careful analysis of the many desired properties for an effective pipe coating. The National Association of Corrosion Engineers clearly defines the specific qualities that a pipe coating should possess in NACE Standard RP-01-69, Section 5: Coatings.[2]

Let us first review the desirable characteristics of a pipe coating:

1. Effective Electrical Insulator

Since soil corrosion is an electrochemical process in which an electrical current flows from the structure to the soil carrying metallic ions with the flow of current, a pipe coating has to stop this current by effectively isolating the structure from the environment.

2. Ease of Application to Pipe

The coating material must be suitable for the intended service and properly applied to be effective. There are many excellent pipe coatings that require exacting application procedures that are difficult to maintain. Consistent quality may best be obtained with a coating system that is least affected by variables. Coating application specifications and good construction practices combined with proper inspection contribute to the quality of the finished coating system.

3. Applicable to Piping with a Minimum of Defects

This characteristic correlates with ease of application. No coating is perfect, and that is why cathodic protection is required; however, no one wants to buy a pipe coating that has too many holidays (voids in coating) even before it leaves the mill.

4. Good Adhesion to Pipe Surface

Coating adhesion is important to eliminate water migration between the metal substrate and the pipe coating. The coating adhesion assures permanence and ability to withstand handling during installation without losing effectiveness.

5. Ability to Resist Development of Holidays with Time

Once the coating is buried, two areas that may destroy or degrade coatings are soil stress and environmental contaminants. Soil stress, brought about in certain soils that are alternately wet and dry, creates tremendous forces that may split, bog or cause thin areas. Adhesion, cohesion and tensile strength are important properties to evaluate in order to minimize this problem. The coating's resistance to chemicals, hydrocarbons, acidic or alkaline conditions has to be known in order to evaluate performance in known contaminated soils.

6. Ability to Withstand Normal Handling, Storage and Installation

The ability of a coating to withstand damage is a function of its impact, abrasion and ductile properties. Pipe coatings are subjected to a great deal of handling between the time of application to the time of backfill. While precautionary measures of proper handling, shipping and stockpiling are recommended, the coatings vary in their ability to resist damage. Outside storage requires resistance to ultraviolet rays and temperature changes. These properties must be known and evaluated to assure proper performance.

7. Ability to Maintain Substantially Constant Electrical Resistivity with Time

Since corrosion is an electrochemical reaction, a coating with a high electrical resistance over the life of the system is important. The percentage of initial resistance drop is not as indicative of the pipe coating quality as is the overall level of electrical resistivity.

8. Resistance to Disbonding when under Cathodic Protection

Since most pipelines will eventually be cathodically protected, it is necessary for the coating to be able to withstand cathodic disbondment. The amount of cathodic protection required is directly proportional to the quality and integrity of the coating. Considering interference and stray current problems, this becomes a most important requirement.

Cathodic protection does two things to a coating. First, it has the ability to drive water through a coating which would ordinarily resist such penetration. Second, it may produce hydrogen at the metal surface whenever current reaches it and the hydrogen in turn will break the bond between the coating and the metal surface. While no coating is completely resistant to damage by cathodic protection, it is very important that we choose a coating that will minimize these effects.

The ASTM G8-72 test for Cathodic Disbonding of Pipeline Coatings, commonly known as the salt crock test, is a method used to measure a coating's resistance to damage by cathodic protection. An intentional holiday is placed in the coating being evaluated and the sample is immersed in a 3 percent salt solution (1% sodium carbonate, 1% sodium sulfate, and 1% sodium chloride.) Then when a negative electrical potential is applied through the aqueous salt solution by means of an anode or rectifier, an electrical current will flow through the solution to the bare metal surface as it would in actual use. The sample is maintained at a constant potential and the current drain that is required to protect the sample is measured periodically. After a period of 30 to 90 days, the sample is removed and examined for undercutting or any discontinuities. These discontinuities are easily identified by an accumulated calcite deposit around them. Relative resistance of the coating to cathodic protection is determined by the number of unintentional holidays, by the amount or increase in current that has been flowing and by the amount of cathodic disbondment or undercutting that has occurred around the intentional holidays. The difference in the reaction to this test by various coatings is sometimes very vivid. In some cases, such a quantity of water is driven through the coating that the coating develops large water blisters all around the sample. Then, in other cases, the cathodic disbondment around the intentional holiday is so great as to cause the entire sample to become disbonded from the surface. Then, of course, some samples experience very frequent unintentional holidays. Some coatings, on the other hand, exhibit no unintentional holidays, very little water being driven through the coating and almost no cathodic disbondment around the intentional holiday.[3]

9. Ease of Repair

Recognizing that some damage may occur, as well as the necessity of field coating the weld area, compatible field materials are required to make repairs and complete the coating after welding. Manufacturers' recommendations should be followed. Field condition variables will influence your selection of materials.

All nine of these properties are necessary and it is impossible to cite one as being the most important, as they all contribute to a successful pipe coating. However, perhaps we can agree that one property not specifically listed under this recommended practice has the most influence on performance, and that is resistance to water penetration. Once in its environment, water penetration will effect performance in that absorbed moisture will carry electrical current through the coating material and therefore, the electrical resistance will be reduced. A rather simple test is often used to determine water absorption and that is to measure weight gain following immersion for a specific period of time. This test is not recommended, as the results are not necessarily valid for evaluation comparison of different coating systems. Factors to consider in this method are that some coating materials could be dissolving ingredients at the same time they are absorbing water. Therefore, a net weight increase would not be indicative of water absorption. The thickness and the composition of the coating material would also be a factor to consider in this method of evaluating coating systems based on water absorption. A more accurate method is the ASTM G9-72 standard method of test for water penetration into pipeline coatings. "This method consists of an immersion-type test where pipe specimens are suspended in an aqueous electrolyte for the duration of the test period. Electrical measurements of coating capacitance and dissipation factor are used to follow the water absorption rate of the test materials."[4]

The following factors should also be considered when selecting a pipe coating.[5]

1. Type of soil or back fill
2. Accessibility of pipeline
3. Operating temperature of piping
4. Ambient temperatures during construction and installation
5. Geographical and physical location
6. Handling required and storage conditions
7. Costs

Evaluation of pipe coating properties coordinated with the above considerations will assist in the selection process. Of the above factors, the most misunderstood one is "costs". In pipe coating economics as in all cost analysis, the end has to justify the means. In other words, the added cost of coatings and cathodic protection has to earn its way by paying for itself through reduced operating costs and longer life. "True" protection costs should not only include initial costs of coating and cathodic protection but also installation, joint coatings and repairs.[6] Field engineering and facilities to correct possible damage to other underground facilities that may be damaged by increases in current requirements may add additional costs, possibly even outweighing the initial costs of the pipe coating.[7] Another well known expression "that you get what you pay for" certainly has application to the purchase of pipe coatings.

We have defined the purpose of a protective coating and have detailed the desirable properties of an effective pipe coating. If any one coating excelled in all these properties, it would be a perfect pipe coating. Suffice it to say, we are still striving to design the perfect pipe coating.

How can you best select the pipe coating to meet your requirements? Experience has proven a reliable method but how much experience, 20 years? it has been approximately 23 years since the plastic coatings have become available and only 5 to 7 years that present formulations have been on the market. Many companies utilize accelerated tests as established by ASTM to enable them to make a quantitative evaluation of these properties. You as a user have to weigh the importance of these properties in light of your own conditions.

We will now look at the different coatings available, describe their properties and then how they are applied.

1. Enamels

The bituminous enamels are formulated from coal tar pitches or petroleum asphalts and have been widely used as protective coatings for over sixty-five years. Coal tar and asphalt enamels are available in summer or winter grades. These enamels are the corrosion coating; they are combined in various combinations of glass and/or felt to obtain mechanical strength for handling. You should also specify that these materials meet requirements such as National Association of Corrosion Engineers, National Association of Pipe

Coating Applicators, or the American Water Works Association. The enamel coatings have been the workhorse coatings of the industry; and, when properly selected and applied, can provide efficient, long-life corrosion protection.

Enamel systems may be designed for installation and use within an operating temperature range of 30°F to 180°F (-1.1°C to 82°C). When temperatures fall below 40°F (4.4°C), added precautions should be taken to prevent cracking and disbonding during field installation. Enamels are effected by ultraviolet rays and should be protected by kraft paper of white wash. Enamels are effected by hydrocarbons, and the use of a barrier coat is recommended when known contamination exists. This coating is available on all sizes of pipe. In recent years, the use of enamels has declined for the following reasons:[8,9]

1. Reduced number of suppliers,
2. Restrictive O.S.H.A., E.P.A., and F.D.A. environmental and health standards,
3. Increased acceptance of plastic coating materials, and
4. Alternate utilization of raw materials as a fuel.

For all pipe coatings, pipe should be ordered bare, free of mill coatings, to permit the best surface preparation. Prior to blast cleaning the pipe is heated to drive off surface moisture and loosen mill scale. The blast cleaning will use sand or steel shot or grit or a combination of both to obtain the desired profile and cleaned surface. Blasting operations shall remove all rust, scale and other impurities from the surface, exposing base metal over all, which presents a grayish matte appearance between Steel Structures Painting Council Standard SP-6 and SP-10. This is equivalent to NACE Standard TM-01, Visual Standards, between NACE No. 3 and NACE No. 2.

The blast cleaned surface is primed by brush, spray or by use of a priming rag commonly known as a "granny rag." When the primer has dried sufficiently, the coating and wrapping is performed by the hot application of a bituminous coating which is pumped from the coating machine through what is commonly called a spreader, from which the coating flows in a flood coat onto the surface of the pipe. One important factor is to be sure that the coating material is melted down properly and brought to application temperature gradually. This is accomplished in an agitated kettle.

Agitation is needed to maintain uniform heat and to prevent the mineral fillers (25 to 35 percent) from settling out. Settling of the fillers may tend to develop what are known as hot spots, or carbon spots on the bottom of the kettle. These small carbon spots will break down and get into the coating material and eventually cause jeeps or holidays in the line. Carbon spots are cathodic to the metal and will cause the metal to pit. Thus, the melting operation and the mechanical agitators are of extreme importance.[10]

An asbestos felt wrapper has generally been used as the outer wrap but with restrictions on asbestos as a carcinogen, it is being replaced by a glass wrapper. Care must be taken in application of the glass wrap, that it is properly encapsulated with enamel to prevent a wicking action of moisture from the environment to the steel.

Mill wrapping has many variations in specifications as to the various types of bituminous coating materials which are applied to a nominal 3/32" (.24 cm) thickness, followed by the glass or asbestos felt or combination of both. Multiple coatings of enamel are often applied to build up the total thickness where greater protection is required.

An electrical inspection of the completed coating should be made in accordance with the procedures established by NACE Standard RP-02-74, Recommended Practice for "High Voltage Electrical Inspection of Pipeline Coatings."

For a more detailed treatment of this subject the ANSI/AWWA C203-78 American National Standard for Coal-Tar Protective Coatings is recommended.

2. Asphalt Mastic

Asphalt Mastic pipe coating is a dense, mixture of sand, crushed limestone and fiber bound together with a select, air blown asphalt. These materials are proportioned to secure a maximum density of approximately 132 pounds per cubic foot. This mastic material is available with various types of asphalt. Selection is based on operating temperature and climate conditions to obtain maximum flexibility and operating characteristics. This coating is a thick, 1/2" to 5/8" (1.27 cm to 1.6 cm) extruded mastic resulting in a seamless corrosion coating.

Extruded asphalt mastic pipe coating has been in use for over fifty years. It is the thickest of the corrosion coatings and is cost effective for offshore installations. Its ability to dissipate heat while providing a relatively holiday free coating, has made it the most used pipe coating for pipe type cable installations.[11]

Asphalt mastic systems may be designed for installation and use within an operating temperature range of 40°F to 190°F (4.44°C to 88°C). Precautionary measures should be taken when handling in freezing temperatures. Whitewash is used to protect it from ultraviolet rays, and this should be maintained when in storage. This system is not intended for above ground use or in hydrocarbon contaminated soils. This coating is available on 4-½" to 48" O.D. (Optical Density) (11.4 cm to 122 cm) pipe.

The application procedure is as follows:[12]

Prior to blast cleaning the pipe is heated to drive off surface moisture and loosen mill scale. The blast cleaning is accomplished by a combination of shot and grit to remove all rust, scale and other impurities from the surface, exposing base metal over all, which presents a grayish matte appearance between Steel Structures Painting Council Standard SP-6 and SP-10. (NACE No. 2, NACE No. 3). Pipe is then spray coated with an asphalt primer prior to extrusion of the hot mastic mix to the circumference of the pipe. This is a continuous extrusion which forms a seamless coating bonded to the pipe. Whitewash is applied to reflect the sun's rays and to facilitate stockpiling. An electrical inspection of the completed coating should be made in accordance with the procedures established by NACE Standard RP-02-74. Recommended Practice for "High Voltage Electrical Inspection of Pipeline Coatings." Holidays are patched and retested. Patching is relatively easy, because the mastic is thermoplastic, it is heated and worked with a trowel to reseal.

3. Extruded Plastics - Polyethylene and Polypropylene

The extruded plastic coatings have been available to the industry since 1956 and their growth and acceptance has been remarkable during this period. Initial problems of stress cracking and shrinkage have been minimized by better quality and grade of high molecular weight polyethylene resins. There are presently two systems available in the United States. One is an extruded polyethylene sleeve which is shrunk over a 10 mil asphalt mastic, and the other is a dual extrusion, where a butyl adhesive is extruded onto the blast cleaned pipe followed by multiple fused layers of polyethylene. The latter method utilizes multiple extruders in a proprietary method which obtains maximum bond with minimum stress. The sleeve type is available on 1/2" through 24" O.D. (1.3 cm to 61 cm) pipe, while the dual extrusion is presently available on 2½" through 103" (6.35 to 262 cm) pipe. The operating temperatures range for polyethylene systems from -40°F to 180°F (-40°C to 82°C) and for polypropylene it is -5°F to 190°F (-21°C to 88°C). The polyethylene systems have been successfully field bent (1.9° per pipe diameter length) at -40°F (-40°C). Swelling may occur in hydrocarbon environments. Polyethylene has excellent dielectric strength. With the proper selection of polyethylene resins and the addition of 2½ percent carbon black, the dual extrusion system has withstood long term aboveground storage and aboveground use. An electrical inspection of the completed coating should be made in accordance with NACE Standard RP-02-74 Recommended Practice for "High Voltage Electrical Inspection of Pipeline Coatings."

The application methods are as follows:

Both methods preheat bare pipe prior to grit blast cleaning to a commercial blast clean. With the sleeve type coating, the adhesive undercoating is applied by flood-coating the hot material over the pipe before it passes through an adjustable wiper ring which controls the thickness. After the mastic is applied, the pipe passes through the center of the crosshead die where the plastic is water quenched to shrink it around the undercoating and pipe. Following electrical inspection, pipe ends are trimmed for cut back and the coated pipe is stockpiled.

In the dual extrusion system, the cleaned pipe is rotated at a calibrated rate through the process. The first of two extruders applies a film of butyl adhesive of predetermined width and thickness, fusing the film to the rotating pipe in two layers. While the butyl is still in a molten state, high molecular weight polyethylene is applied from the second extruder in multiple layers of a predetermined thickness, producing a bonded coating 50 to 100 mils thick. Water quenching, electrical inspection and cut back is completed prior to stockpiling.

Polyethylene systems have been in use in Europe for approximately fifteen years with both crosshead and side extrusion methods. In addition to the butyl adhesive or asphalt mastic adhesive, some systems use a polyethylene copolymer adhesive. This system requires high temperature 200°C (390°F) heating for application of the adhesive.[13]

For a more detailed treatment of extruded plastic pipe coating systems the reader is referred to the paper "Extruded Plastic Pipeline Coatings.[14]

4. Fusion Bonded Thermosetting Powder Resins

Fusion bonded powder pipe coatings were first introduced in 1959 and have been commercially available since 1961. These coatings are applied to preheated pipe surfaces 400°F to 500°F (204°C to 260°C) with and without primers. On some resins, post curing is required for complete cure. This coating is applied in a 12 to 25 mil thickness. The fusion bonded powder coatings exhibit good mechanical and physical properties and may be used above or below ground. Experience has indicated that on above ground installations, to eliminate chalking and for longer service life, it is recommended to topcoat with a urethane type paint system. Of all the pipe coating systems, the fusion bonded thermosetting resin systems, when properly applied are the most resistant to hydrocarbons, acids and alkalies.

Perhaps the main advantage of the fusion bonded powder pipe coatings is that they cannot cover up apparent steel defects because of their lack of thickness, so they do permit excellent inspection of the steel surface before and after coating. The amount of holidays that may occur is a function of the surface condition and the thickness of the coating specified. A recent steel surface profile study by Dr. Bruno and Ray Weaver of the Steel Structures Painting Council (SSPC) found the following effect of blast cleaning on steel: "Dr. Bruno and Ray Weaver of the SSPC explained that viewing shot or grit blasted surfaces in three dimensions reveals surface characteristics not visible in two dimensions. SSPC research has uncovered the existence of abrasive-formed spikes of steel that protrude from one to ten mils from the surface.

SSPC researchers have dubbed these phenomenons "hackles" and believe that they are formed by the cutting action of the abrasive. Weaver said that a hackle may be created when a piece of abrasive strikes a work stress area. In three dimensions, the hackle stands out in stark relief against its surroundings, but is barely visible in two dimensions.

Dr. Bruno said that hackles are difficult to locate and unpredictable. One never knows how many one will find in any given area of surface studied, he said, and their effect on coatings is not known."[15]

Increasing the thickness of the applied coating minimizes this problem and with minimum cathodic disbondment characteristics, it has proven to be a most serviceable pipe coating. These coatings are available on 3/4" - 48" (1.9 cm - 122 cm) O.D. pipe.

The application procedures for thermal bonded powder resins are less tolerable of variables and more care is required to properly apply them. Prior to cleaning, pipe is heated to remove moisture and loosen mill scale. It is necessary to clean the surface to a near-white metal finish as defined in SSPC-SP10 (NACE No. 2).

Pipe is then heated uniformly to the recommended application temperature (400°F - 500°F/204°C - 260°C). Each material has its own requirements and tolerance level which must be strictly adhered to. If a primer is required there are minimum maximum overcoat times which are necessary to follow. The powdered resin is applied by electrostatic deposition to the 12-25 mil thickness specified. Certain resins require post heat treatment for proper cure. Inspection by a minimum of 100 volts per mil of thickness is recommended. Pipe requiring limited repair (to be agreed to between customer and applicator, perhaps one holiday per ten square feet) due to hackles, coating imperfections and other minor defects shall be repaired by use of a heat bondable polymeric hot metal patch stick. A 100 percent solids liquid epoxy repair material is recommended within 12" of each end of pipe. Manufacturers recommendations for field application of patching materials should be followed.

For a more detailed treatment on Fusion Bonded Thermosetting Powder Resins, the reader is referred to the ANSI/AWWA C215-78 standard.

5. Liquid Epoxy and Phenolics

There are many different liquid systems available today that cure by heat and/or chemical reactions; some are solvent types and others 100 percent solids. Their use is mostly on larger diameter pipes where conventional systems may not be available or where they may offer better resistance to operating temperatures in the 200°F (90°C) range.

Generally epoxies have an amine or a polyamide curing agent and require a near-white blast cleaned surface SSPC-SP10, (NACE No. 2). Coal tar epoxies have coal tar pitch added to the epoxy resin. A coal tar epoxy cured with a low molecular weight amine is especially resistant to an alkaline environment such as occurs on a cathodically protected structure. Some coal tar epoxies become brittle when exposed to sunlight.[16]

The application for a mill-applied system is as follows: The pipe is placed on rotating rollers mounted on a tracked dolly which automatically feeds the pipe into a grit blasting machine. It is cleaned inside and out. Then it is transferred into a spray booth where the interior and exterior may be simultaneously coated with two separate spray coats to provide a dry film thickness of 12 mils. After which the coated pipe is then subjected to hot air blowers for proper curing prior to inspection at 100 volts per mil.[17]

6. Tapes

Polyvinyl, polyethylene and coal tar tapes are widely used in the field for joint coating protection or for odd shapes or bends on mill applied applications. The trend has been to heavier butyl-mastic type adhesives to provide better adhesion and eliminate water migration at the overlap. When tapes are applied at a coating plant, padding or rockshield must be provided to minimize shipping damage. Over the trench, field applied tapes may be applied with tape wrapping machines. Coatings applied over the ditch are less susceptible to physical damage because of reduced handling, but they can be more affected by variations in ambient temperatures and humidity. These along with inadequate surface preparation are the main disadvantages of a field applied coating system. The important developments in plastic tapes have been an increase in their thickness, use of stronger resins and improved adhesion by the use of new types of adhesives and primers. Mill applied tapes capable of service temperatures to 210°F (99°C) are presently available and have had limited use.

7. Wax Coatings

Presently not too much is heard regarding the use of wax coatings. However, they have been in use over 48 years and are still utilized on a limited basis. Microcrystalline wax coatings are usually used with a plastic overwrap. The wax waterproofs the pipe and the wrapper protects the wax coating from contact with the soil and affords some mechanical protection. The most popular use of a wax coating is the over-the-ditch application with a combination machine which cleans, coats, wraps and lowers into the ditch in one operation. The fact that there are no objectionable or toxic fumes or smoke present should make this system more acceptable.

8. Polyurethane Foam Insulation

Efficient pipeline insulation has grown increasingly important as a means of operating hot and cold service pipelines. This is a system controlling heat transfer in above or below ground and marine pipelines. While generally used in conjunction with a corrosion coating, if the proper moisture vapor barrier is used over the urethane foam, effective corrosion protection is obtained. This is a plant applied process, where the carrier pipe is centered within the outer jacket which contains and molds the foam as well as providing an effective moisture vapor barrier. Metered quantities of foam components are rapidly introduced between the carrier pipe and the outer jacket. The foam is restrained by end caps and rises on a first-in basis forming a uniform composite unit. When properly jacketed, usually with polyethylene or coated steel, the system is moisture and corrosion resistant and sufficiently strong to resist crushing and flexible enough to permit allowable field bending.[18]

9. Concrete

Mortar lined and coated pipe have the longest history of use to protect steel or wrought iron from corrosion.[19] When steel is encased in concrete, a protective iron oxide film forms. As long as the alkalinity is maintained and the concrete is impermeable to chlorides and oxygen, corrosion protection is obtained. See AWWA C-205 for a detailed reference on concrete coatings.

Today concrete as a corrosion coating is mainly limited to internal lining. The external application is applied over a corrosion coating for armor protection and negative bouyancy in marine environments. A continuous reinforced concrete coating has proved to be the most effective controlled method of obtaining desired results.

Materials including water, sand and/or heavy aggregate, and cement are mixed in the application plant. The materials are conveyed by belt to the throwing heads where controlled-speed belt/brushes throw the mixture onto the coated pipe surface. The rotating pipe is moved past the throwing heads to receive the specified thickness of concrete. Simultaneously the galvanized wire reinforcement is applied with an overlap. To further increase tensile strength and to improve impact resistance additional layers of wire or steel fibers may be specified.[20]

We have now covered the most popular protective coatings and described their properties and how they are applied, but I would be remiss if I stopped here. In the foreword to the N.A.C.E. recommended practice "Application of Organic Coatings to the External Surface of Steel Pipe for Underground Service," I quote, "Experience Shows that a Major Cause of Pipeline Coating Failure is due to Improper Application."[21] Therefore the selection of an applicator might prove to be the most important consideration. A quality material poorly applied is of little value and the quality of your pipe coating is only as good as the quality of application. To assist you in your evaluation of an applicator, the following points should be considered:[22]

1. Experience
2. Reputation
3. Reliability
4. Conformance to coating manufacturers specification
5. Modern automated equipment
6. Quality control

1. Experience

A lot of research and also trial and error has gone into the development of every coating that is now on the market. This has required close cooperation between applicator, coating manufacturer, equipment manufacturer and customer. The transition from laboratory to production line is usually a costly experience but the value of having accomplished this cannot be underestimated.

2. Reputation

This is an asset that has to be earned through performance as promised.

3. Reliability

Consistent quality performance that can be depended upon.

4. Conformance to Coating Manufacturers Specifications

Manufacturers have established minimum specifications for application of their materials which should be met, if not exceeded.

5. Modern Automated Equipment

Capital expenditure on automated application equipment has been an important part of the overall success of plastic coatings. The elimination of human errors through automation and controls will continue to be an important factor in obtaining improved pipe coatings.

6. Quality Control

Conformance to specifications has to be checked regularly. Knowledge of applicators quality control procedures on materials, application and finished product are essential in the selection of an applicator.

To summarize, it is not an easy task to select the "best" coating system for your needs. This selection requires knowledge of your operating and installation conditions to be able to evaluate the properties of the pipe coatings as to filling these needs. I reemphasize that selection of a quality applicator is the most important consideration and frequently is the most neglected. After the coating and applicator have been selected, inspection at the coating mill and especially during construction phases will go far in assuring that you are obtaining maximum benefits from your pipe coating system.

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DISCUSSION ON PIPELINE WRAP

QUESTION (Mr. Ward): You talked a lot about oil pipelines and heat waste pipeline applications underground. Would you address the aboveground or in-plant steam pipes?

ANSWER (Mr. Wink): I did overlook that big market. Cross-country pipeline is basically what I talked about because that is what I am most familiar with. When you get to your petrochemical plants, utility plants, or another type of industry, you have overhead pipelines. There is a different corrosion problem as opposed to being in the soil. Different types of coatings must be looked at. Most predominant is the phenolic epoxy, a liquid type coating that is sprayed on.

One important thing to consider is the temperature of the line. You mentioned steam, which can be 800 or 900 degrees; a very special painting is needed for this in order to withstand the heat and prevent the pipe from disbonding. Napguard could possibly handle temperatures of that nature.

Coatings undergo worse corrosion aboveground than with a buried pipeline and maintenance is probably a year-around aspect of this type of situation.

QUESTION (Mr. Ward): I am also thinking of thermal insulation.

ANSWER (Mr. Wink): For thermal insulation, polyurethane foam is good up to about 300 degrees Fahrenheit. With steam lines, which have high temperatures, you probably want to look at calcium silcate.

QUESTION (Mr. Castleman): I would like to know how long polyurethane foam has been around, and was asbestos insulation used before the polyurethane foam?

ANSWER (Mr. Wink): I am really not familiar with asbestos being used as an insulation.

QUESTION (Mr. Castleman): I mean underground.

ANSWER (Mr. Wink): Polyurethane foam, to the best of my knowledge, has been used since the early 1950s. I know a couple of jobs overseas where urethane foam was used, but it primarily replaced calcium silcate, which is a very brittle pipe insulating material.

QUESTION (Ms. Levy): I am from the Health Standards Bureau of OSHA. This is a general question to all the members of the panel. I have heard a lot now, and I am encouraged by hearing that you have new substitutes for asbestos. I would like to know to what extent you are thinking about new processes, that is, rather than just plugging in a substitute for asbestos, are you looking at materials that would change exposure levels. Is any research being done in that area?

ANSWER (Mr. Wink): I will try to attack the question from my standpoint and then I will pass it on. Primarily, whereas applicators are concerned, the affect of asbestos in our industry is small — it is more in the manufacturing aspect. In one material we replaced asbestos with fiber glass, and primarily, that is what the pipeline industry will do--just replace asbestos with other material.

QUESTION (Mr. Bailie): Is your question to change the process of production to handle asbestos or is it to change the process completely to eliminate asbestos?

QUESTION (Ms. Levy): Well, I am unclear as to how much asbestos you are going to eliminate, but from what I have gathered, some of the substitutes will still involve exposures. There is still going to be some exposure unless you change the workers' direct contact to some extent, and I am curious about how that is going to come about, if at all, and is there any ongoing research?

ANSWER (Mr. Bailie): Relative to the roofing industry, the exposure to asbestos is rather minimal. It is more prevalent at the production point. To that end, I cannot speak with any authority. I am sure that your department has leaned heavily on the producers of asbestos felt to the point that they are taking every precaution in changing their process.

REMARK (Chairman Guimond): If I interpret you correctly, you are saying that where you may have a process now that is using asbestos or some other kind of fiber, such as fiber glass or mica, either as a filler or as a binder, are companies changing the processes of making those pipes or insulations so that the whole system might be enclosed, so as to eliminate exposure.

REMARK (Ms. Levy): Right.

ANSWER (Mr. Bailie): I can only say this, in the area in which our corporation uses asbestos, we have spent a lot of money to, first of all, comply with your requirements, and second, to provide as much protection as is possible for the workers involved. I think that can also hold true for the producer of roofing felt.

QUESTION (Chairman Guimond): You have indicated that there seems to be a transition occurring from asbestos to alternative materials. Do you know approximately what fraction of the market these alternatives have at the present time?

ANSWER (Mr. Wink): I would guess, offhand, the coal tar industry, which is the biggest user of asbestos, is now using fiber glass. This is about 50 to 55 percent of the pipeline industry. The other coatings comprise the remaining 45 to 50 percent.

TEXTILES

by

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ABSTRACT

Many U.S. companies, some of them former asbestos weavers, have expended effort into the development of products to replace asbestos textiles. Aramids, ceramic fiber, fiberglass and silica have all been processed into textiles which have gained acceptance as substitutes in many applications.

Major uses for asbestos textiles have been as gaskets, packings, heat shields and personal protection. Current replacement products have certain, but not all, performance characteristics necessary to be suitable substitutes in all applications. Silica and ceramic fiber products, for example, resist extremely high temperature and most chemicals but will not withstand abrasive conditions. Inversely, aramids, while possessing good strength and mechanical resistance, can only be used in temperatures under 650°F.

In most cases, non-asbestos substitutes are more expensive than the asbestos products they replace. For certain uses, the additional cost is economically justified by a longer service life. In applications where performance is relatively equal, health and environmental considerations are usually the justification.

While many substitutes are available, no one particular product can be used to replace asbestos in every application. Careful consideration of the application is necessary to determine the appropriate substitute.

My product today is TEXTILES -- Asbestos Replacement Textiles in particular. I guess it may be somewhat bold, but it is safe to say that there is now a replacement for every asbestos textile product. When I first became associated with asbestos replacement, price and performance seemed to be the problem areas. These are no longer problem areas. There are products that are very price-competitive and there are products that perform better than asbestos. My discussions today will not cover friction-oriented textile products such as clutch facings and brake lining materials. Additionally, I will not talk about dynamic packings. These topics have been covered earlier. The areas I am going to cover are the woven cloth and tapes, ropes and braids, tapes and sleevings.

The market is big -- very big -- much bigger than most people would think for this particular product line. We conservatively estimate yearly purchases of \$50 to \$70 million dollars or 5 to 6 million pounds a year for just textiles. The business is big with innumerable applications. The applications are welding cloth, maintenance cloth, furnace curtains, expansion joints, static packings and general packings, furnace door seals, flange gaskets, burner gaskets, boiler door seals, pipe wrapping and cable protection, safety garments, gloves and insulation sales. So far, replacement textile products have penetrated only 10 percent. The big problems are marketing and user expectations. It starts with the user who purchases from a fabricator or distributor who is supplied by the manufacturer. The user is the key person. He's really unsure of his service conditions. Asbestos always worked and was specified. Asbestos textiles have been maintained items. It was always on hand and used universally. It always worked and it was always specified for key engineered applications.

Direct substitution is difficult. You just cannot throw in a replacement product where an asbestos product used to be and expect the exact same performance. Application-by-application replacement is necessary. Usually traditional mill supply houses, or asbestos specialty distributors stocked and delivered. The user must now deal with other people. The forms may be different. Instead of a 40 inch cloth, he may now have to use a 36 inch cloth. Or he may want to use a paper or a felt to do a job.

There is really little incentive. What sort of pressure are we putting on people? The dangers aren't really apparent. You see asbestos and do not take it seriously. "I'm not going to get that fiber into my lungs. What are the chances of that one fiber getting in there?" A lot of people think that way. However, there is a lot of pressure from the foremen and the superintendents to keep the production up. Trying new products causes problems that affect production. This is a big hurdle to overcome. They want something that is better and cheaper, rather than safer and acceptable.

In regard to the fabricator, they are not too anxious to change either. They have to come up with new methods. Asbestos used to crease when they were making their blankets. Substitutes do not crease too well. New methods have to be used -- new molds, dies, new forms. Wetting agents are required for coating whereas plain water or mortar was used before. Problems exist with irritability, abrasion and dust.

From the distributor standpoint, these are the people who have to sell the product to the end user. They need to stock more products now. Before they used to stock one or two different types of asbestos cloth and that took care of all the needs. Now they have to stock maybe 4 or 5 different products and that is not too attractive. That is more inventory, more dollars. They are unsure how willing the customers are going to accept and how willing they are to convert or what they are going to convert to. They need more initial service and selling effort to convert the customer. That means more salesmen and more field service. This means more people or more overhead. Profitability requirement for price, discount, and service are different. They're different for the different types of distributors.

The manufacturers, the people who make these textile products, they really do not know the end uses. For so long asbestos manufacturers have been a material supplier. The fabricators and distributors really know the nitty gritty application details. Manufacturers supplied asbestos and asbestos worked. What are the real needs of the end user? What are his service requirements? Does the end user really know whether his pipeline is 500 degrees or 300 degrees? Is the door seal going to see 1000 degrees or really only 600 degrees, or maybe 1500 degrees? They do not have the knowledge of the real user problems. The manufacturers have to develop replacements but do not know the key applications and the key service requirements. They are held to a specification written around asbestos. When you try to make a product that is around an asbestos specification and the product is not asbestos, it is very difficult to duplicate. But it is possible to meet the service requirements with different materials and forms.

The manufacturers are not familiar with the fabricators, or the distributors of the end users' needs. Some need price, discount, service and some need different types of performance requirements. Application selling is required by the manufacturers. They have to invest in people to get to the individual accounts, and the individual end users to find all those applications one by one and determine what product can replace the asbestos. These are what I consider the major problems in replacing asbestos textiles.

Let me talk a little bit about the products available and some of the requirements necessary for them. Replacement products have three common requirements. They must be temperature resistant, inflammable and flexible. Cloth products need molten metal resistance, wear and abrasion resistance, the ability to be fabricated and mechanical strength. Some examples are welding curtains, maintenance blankets, slow cool blankets, expansion joints and furnace curtains. Packings need resiliency, chemical stability, durability, abrasion resistance and the ability to be coated. Some static packings used to prevent leaking of gasses, must have good sealability, compressibility and recovery characteristics. Burner gaskets and pipe wrappings need good mechanical strength, vibration strength and molten splash resistance. Clothing must be non-irritating, coatable and easy to fabricate.

There are several types of fibers that are being used for asbestos substitution.

Fiberglass is currently very popular with a wide range of acceptance. It can be used very successfully in certain applications. Advantages are: it has moderate thermal resistance, 1000 degrees, it can be blended with other fibers, it is relatively low cost and it has good mechanical strength. The disadvantages are: it has poor abrasion resistance at higher temperatures, it has limited molten metal resistance, it is irritating to workers' skin, and it has poor sealability. These are not concrete advantages and disadvantages. In each application the advantages and disadvantages may be different. Some of the leading contenders--for example PPG and Owens Corning--seem to be the strong supporters of asbestos replacement textile fiberglass. PPG has introduced Texto and Owens Corning also has texturized fiberglass products. The texturized product is a product that was developed, in my estimation, to look similar to asbestos and to provide thermal insulation characteristics. Many users are finding that non-texturized fiberglass or continuous yarn fiberglass products are well accepted in the marketplace. It is a trend toward people being open minded. A product does not necessarily have to look like asbestos in order to substitute for asbestos. Some of the products made from this are Zetex fiberglass cloth and Uentley Harris rope products.

The advantages of ceramic fiber are good heat resistance (it withstands 2300 degress without any degradation and can withstand temperatures up to 3000 degrees), it is inflammable, it has good thermal shock resistance, it has molten metal resistance, it can be blended with other material. It has good mechanical strength, good chemical resistance, and can be coated and fabricated. Major disadvantages are its abrasion resistance, it needs organic carriers to be formed and it is abrasive. There is one form that 3M produces that does not have an organic carrier. It is a continuous form as opposed to a staple. Another form of this is leached silica fiber. The advantages here are good heat resistance, heat resistance to 1800 degrees, inflammability and good molten metal resistance. Disadvantages are that they are brittle at the higher temperature, have poor abrasion resistance and are moderately high cost. New aramids have heat resistance to 600 degrees, have high strenth in the Kevlar form, are non-abrasive, can be blended with other fibers and have good sealability. Aramids are good in the packing areas. Disadvantages are low strength (Nomex), they are difficult to weave and cut (Kevlar) and they are moderately high cost. Some of the leached silicas are Refrasil and Siltemp. The aramids are Nomex and Kevlar, both made by Dupont. Amatex also fabricates aramids into a line of textile products. Other new fibers are carbon fibers which have good thermal properties, sealability and lubricity. Disadvantages are lack of flexibility, poor abrasion resistance, limited vibration resistance, and very high cost. Another fiber is stabilized PAN or better known are the Preox materials. Advantages are flexibility, vibration resistance, good tear strength and good fabrication characteristics. Disadvantages are heat resistance, molten metal resistance, cyanide formation upon heating, and high cost.

Carborundum feels very strongly and is committed very seriously to ending the no asbestos blues. We feel strongly that asbestos can be substituted for. We are heavily committed to this right now and have a line of textile, paper, board and cement products. Our feeling is that if people are open minded about changing the form it does not necessarily have to be a textile to serve the need.

For example, we have successfully wrapped pipes with paper as opposed to wrapping it with a textile tape. It is a low cost way to insulate a pipe. The disadvantages are that it does not have a good durability or abrasion resistance. However, if it is covered, it is a low cost way to go about replacing asbestos textiles. Another example is a CalRod heater used by the Navy. Where they formerly used textiles, they now use ceramic paper. Gaskets have been cut out of textile products. They are now being replaced by board and lightweight papers that serve the same need. Board products are replacing textile cloths in the steel industry as splash protection.

Asbestos is a widely used fiber. It has been around a long time and has had over a century for development of uses and applications. The replacements may work but they are not identical to asbestos. People must have the desire to convert.

DISCUSSION ON TEXTILES

QUESTION (Mr. Cronin): I am with the Safety and Health Department of the Steel Workers Union.

My first question is about fiber diameters. I have seen products like your own, for example, manufactured in many different fiber diameters, ranging all the way from 10 to 15 microns on the upper end, down to, for some products, the submicron size. I am wondering first, why would one use a larger diameter in some applications and a smaller diameter fiber in others?

Second, what is the cost differential for those two different kinds of fibers?

ANSWER (Mr. Manfer): The way Carborundum makes fibers and the way most ceramic and fiber glass manufacturers make their product is the longer the fiber, the greater the diameter in a staple form. Usually, the longer the fiber, the more mechanical strength in a product. That is the reason for the long fiber. The short fiber is used for more volume orientation, so you can use it in reinforcing applications, which do not need mechanical strength, but need a heat dissipater.

Cost-wise, I would probably say the short staple, from our vantage point and that of most ceramic manufacturers, is cheaper because it can be produced much faster and in large quantities. A slower process is required to make the longer fiber and it is therefore more expensive.

Are you looking for relative cost differential?

QUESTION (Mr. Cronin): Why would one use very thin fibers at all? What is the reason or advantage for using the fibers about which there have been, at least, some preliminary health questions?

ANSWER (Mr. Manfer): Usually a fine fiber is necessary for insulation. The finer the fiber, the more air void you can create; the more air void, the better the insulator.

QUESTION (Mr. Cronin): Let me ask you one final question. In the very beginning of your talk you said you know of a nonasbestos textile replacement for every asbestos use. Is there a nonrespirable or a thick fiber replacement, and let us define that as being more than 5 micrometers, for every current asbestos textile use.

ANSWER (Mr. Manfer): I am not sure.

QUESTION (Mr. Cronin): Can you, for example, make the insulation layer thicker? For example, can you achieve the same effect as high temperature insulation with thicker fibers and a greater massive insulation as in a thicker insulation layer around a furnace?

ANSWER (Mr. Manfer): Yes, you can. The problem is the thicker the fiber, the less air space you have, and the thicker the material. I know of many fiber glass uses above the 5 micron level. I think they are running about 10 microns. Fiber glass can not replace everything. Ceramic fibers can range from 3 to 10 microns, and they replace a lot of asbestos. I am not exactly sure what the other fibers diameters or lengths are.

QUESTION (Mr. Weiner): I am from the Navy Department.

Did I hear you correctly to say that cyanides come off of carbon fibers, or was that another fiber you talked about?

ANSWER (Mr. Manfer): No, it was stabilized PAN, which is polyacrylic nitrate, also called Preox. It is not off the carbon fibers.

QUESTION (Mr. Castleman): I divide my time between working as a consultant for the Office of Toxic Substances of the Environmental Protection Agency, working for the Environmental Defense Fund, and working for attorneys representing plantiffs in damage suits against the asbestos industry.

I would like to know if Carborundum is feeling pressure from the importers of Amatex, who, as you must know, plays on both sides of the fence and has two asbestos textile plants in Mexican border towns; is this hurting your ability to market your product?

ANSWER (Mr. Manfer): I would say asbestos imports do not help our situation. I cannot specifically say that it has hurt us, I cannot claim any damage, but it does not help.

QUESTION (Mr. Wyblan): I am from the University of Minnesota.

Going back to fiber diameters, do you have a general idea of the range of diameter, say, for something that you are calling 10 microns? What is the range of the size distribution for fibers like that?

ANSWER (Mr. Manfer): I really have to defer that to my technical people.

QUESTION (Mr. Ross): I am from the U.S. Geological Survey.

Let us pursue diameters a little more since you want to replace all asbestos with a product, I assume, that will not cause disease. Yet you do not know much about the fiber diameters. You see, if we start replacing asbestos with substitutes with fiber diameters in the respirable range, then a health problem might arise 20 years from now. I think we should be a little harder nosed about what we are going to replace with what. We could bring a substitute on the market that can be worse than what we replaced.

ANSWER (Mr. Manfer): That is a very good point. Let me put it this way. I do not want to steal anybody's thunder tomorrow who is going to be talking about this product, in particular. We belong to an organization called TIMA, the Thermal Insulation Manufacturers Association. For the last 20 years, they have been doing studies on fiber glass and ceramic products. Ceramic fiber is not new; it has been around since the early 1950's. So far, TIMA has not shown any negative results from ceramic fiber. It is a smooth fiber, it is not like asbestos, and it does not get caught in your lungs; it can be expectorated. The fiber diameter is large enough, usually, so that it gets stuck in your throat before it goes down to the lungs.

Let me assure you that for the last 20 years TIMA has been working with ceramic fiber and fiber glass materials and nothing has been proven. It is difficult to prove a negative--we do not know what will happen in the next 30 years--but for the last 20 years the testing has shown no carcinogenic or ill effects.

QUESTION (Mr. Guy): I am from the Weyhaeuser Company. We have a severe problem with the door gasketing or door seals, under what I would call high temperature applications for 500 to 600°F. Do you still feel that there is an appropriate substitute material? We have trouble with resiliency and, secondarily, with abrasion resistance. The resiliency problem has not been satisfactorily solved with either asbestos material or gasketing door seals, or with the replacement materials.

ANSWER (Mr. Manfer): I definitely think there is a replacement product, and that is one of our best sellers. It is a ceramic rope that is very resilient, in high temperature applications. I am not going to say that I can come in and replace your rope tomorrow, nor will the fiberglass, Siltemp, or aramid people, but we can work with you, anybody can work with you, and over time, you will get a suitable replacement.

QUESTION (Mr. Guy): Do you know if any of these substitutes are silicon-based or have other kinds of internal structures to support them? Or are they straight replacement material?

ANSWER (Mr. Manfer): It is hard to say they are straight replacements because substitution occurs on a application-by-application basis, I am not sure what you mean by silica support.

ASBESTOS SUBSTITUTES IN ROOF COATINGS

by

Dr. Kenneth Brzozowski
Tremco, Inc.
Cleveland, Ohio

ABSTRACT

Asbestos is used in roofing products, and, to a lesser degree, in sealants and caulks for the variety of properties it imparts to these products. Specifically, asbestos is used for sag or flow control, reinforcement, coating hold out, etc. A large number of substitutes have been proposed and offered. None, however, have been found that duplicate the performance of asbestos. The substitutes found most suitable are very costly. In some cases, they are as much as twenty times more expensive.

As with other industries, the building waterproofing industry has been concerned about a possible ban on the use of asbestos in its products. Tremco, as I am sure many other companies marketing waterproofing materials, has been very active in searching for and evaluating the dozens of asbestos substitutes that are presently on the market. Very briefly, let me mention some of the substitutes that have been offered to our industry:

Precipitated Calcium Carbonate

Ground Rice Hulls

Shredded Newspaper/Clay

Shredded Newspaper

Ground Fly Ash

Fumed Silica

Citrus Flour

Polyethylene Fibers

Fiberglass

Let me say at the outset that our search, though long and extensive, has not been completely successful. We have not been able to uncover a material that performs in a manner similar to asbestos. The primary problems that we have encountered with substitutes are:

1. Cost
2. Oil Absorption
3. Sag Resistance
4. Settling
5. Appearance of Product

COST

I will now give a few details on each of these problems. Our experience is that asbestos replacements are priced anywhere from two to twenty times higher than asbestos. Depending on the product the replacement is going into, this translates into a finished cost of between 10 percent and 150 percent higher. These higher costs would obviously have to affect the selling price to the user or consumer.

OIL ABSORPTION

Oil absorption is the amount of oil required to wet or be absorbed by a specific amount of pigment or filler - in this case asbestos or asbestos replacement. The higher the oil absorption of a filler used in a formulation, the greater the viscosity of that coating or sealant or caulking material or whatever. Our experience indicates that most of the substitutes now on the market have lower oil absorption characteristics than asbestos. This means more substitute must be used to achieve the same viscosity in a product. This of course, relates to the cost considerations which I have already mentioned.

SAG RESISTANCE

Sag resistance is the tendency of an applied wet film of material to remain stationary or resist excessive flow. For example, when you apply a paint or caulking to a vertical surface, you want it to remain in place and uniform on the wall or in the vertical joint. Again, we have found many of the substitutes deficient in this property. Even, with very high loading, i.e. large amounts of filler added to the formulation, we have been unable to obtain acceptable sag resistance properties with these substitutes.

SETTLING

Settling is a term used to describe the process in which there is separation of solid material from the vehicle to the bottom of the container. Obviously, excessive settling, especially settling in a short period of time, would make the product unusable. Most asbestos substitutes have not performed well with regard to sag resistance.

APPEARANCE OF PRODUCT

Our experience indicates that products "look" different when asbestos is replaced. We do not view this to be a serious problem, but are cognizant of the fact that our customers would have to be alerted of any change and re-educated in the use of our products should asbestos be removed.

Turning from coating properties to safety considerations, we feel comfortable with using asbestos in our products. Some time ago, we converted to the use of compacted asbestos in our products to reduce the concentrations of asbestos in the air when handling it in our plants. This required some alterations in manufacturing procedures, but was a relatively straightforward change. Further, we require that only whole bags of asbestos be used when a batch of product is manufactured. This causes us to adjust batch sizes to accommodate whole bags, but eliminates the hazard of having opened partially filled bags laying around a plant. We also have installed highly efficient, closed-system exhaust units in all our plants. Asbestos levels in our plants are monitored by Tremco personnel and, in addition, we have outside testing services check our results on a regular basis. Our air samples always indicate that we are orders of magnitude below the maximum safe limits.

While our coating and caulking materials are being applied and when they are in service, the asbestos is locked into the vehicle and presents no hazard.

Thus, from a safety point of view, we see no reason to place a ban on asbestos in the type of products we manufacture.

Despite the technical problems I have mentioned and the lack of hazard we perceive, we are very actively pursuing substitutes for asbestos or ways to eliminate fillers altogether. This year, for example, Tremco introduced what we believe is the first solvent-free asbestos-free roof rejuvenating coating. We were able to accomplish this without a large increase in selling price and without sacrificing performance. It is our intention to continue on this path; namely introducing asbestos free products that perform as well or better than present products with little or no increase in cost. This will be accomplished as our technology allows us and/or new raw materials become available.

However, should a ban be placed on asbestos tomorrow, Tremco would not be out of business. We have asbestos free formulations for all our present products. These products would not perform as well as existing products and would be more costly. Our chief concern is whether the suppliers of the substitutes could produce the enormous amounts of material that would be required if asbestos is banned.

To summarize:

1. We have been unable to discover a single fiber that can be used across our product line as a substitute for asbestos.

2. Formulating techniques and the use of several asbestos substitutes have allowed us to develop product formulas which are asbestos free. These products are inferior in performance and higher in cost when compared to asbestos containing formulations.

3. We feel that asbestos, as presently used in our products, is safe.

4. Tremco is concerned that enough asbestos substitute materials would be available if asbestos is totally banned. Especially since all users would be competing for the best substitute materials.

5. Over a period of time, Tremco expects to phase asbestos out of its products, but only as technology and raw materials become available.

OVERVIEW OF ASBESTOS
SUBSTITUTES IN SEALANTS,
ROOF COATINGS AND CEMENTS

by

Mr. Eric Wormser
The Gibson-Homans Company
Twinsburg, Ohio

ABSTRACT

In spite of extensive research, the industry has not found a raw material that is a satisfactory substitute for asbestos fibre in roof coatings and roof cements. Complicated formulating techniques have been developed by isolated manufacturers of roof coatings and cements that enables them to produce satisfactory products without asbestos. These products are more expensive than those containing asbestos and are of lesser quality. A ban in the near future on asbestos fibre in roof coatings and cements would result in large volumes of vastly inferior products being sold to the public, in the speaker's opinion.

The majority of caulks and sealants currently on the market do not contain asbestos fibre. Reformulation of those caulks and sealants which do contain asbestos fibre should not present a serious problem.

Dr. Brzozowski has given you a technical exposition into the current state of asbestos fibre substitutes in roof coatings, roof cements and sealants. I will give a non-technical overview into the situation. It will take only one minute to discuss the problems of substituting for asbestos in sealants. That is simple. I plan to use the remainder of my time to discuss with you the far more serious and complicated problems of trying to eliminate asbestos fibre in roof coating products.

We are not aware of any significant amounts of asbestos fibre being used in calks and sealants. Mr. Gurtowski did mention some aircraft sealants where asbestos so far has defied substitution. Caulks and sealants are liquid or semi-liquid gap fillers used in building and equipment construction. They are made from elastomers, synthetic or natural oils, bodied into suitable consistency, which may be pourable but more often is much thicker. In our own company we still have a few specialized formulas containing asbestos fibre. In the absence of regulations banning the use of asbestos in caulks and sealants, we have customer resistance in a few cases to making the necessary changes in properties and purchasing specifications, in order to use substitute materials. However, should the use of asbestos fiber no longer be permitted in these products, I do not foresee a serious problem in coming up with acceptable formulas that do not utilize asbestos.

Now let us turn our attention to roof coatings and cements. First I want to explain the difference between these products. Roof coatings are cold applied liquids that are used to rejuvenate and protect almost any type of roof, except usually not the typical home shingle roof. Typical types of buildings utilizing roof coatings are home garages, porch decks, apartment houses, sheds, farm buildings, industrial buildings and commercial buildings of all sorts, including stores, shopping centers and office buildings. These coatings are applied by brush or spray.

Roof cements are trowel applied compounds. Their consistency is similar to soft margarine. They are used to seal openings large enough so that liquid coatings would run through them. Roof cements are used on almost every type of building regardless of the roofing system employed, including the typical shingle roofed home. They are used to seal between vertical and horizontal surfaces and around projections such as vent pipes, chimneys, roof heating and air conditioning units, gutters, and gravel stops, the list is almost endless.

Approximately 65 percent of our company's sales of roof coatings and roof cements go through retail stores to the homeowner and handyman type applicator.

The sheet roofing systems described by speakers are almost universally applied by the professional roofer. Roof coatings and roof cements are used to protect most of these systems also. I do not believe that anyone is suggesting that sheet systems that do not contain asbestos can replace roof coatings and roof cements. Should anyone entertain such an idea, a study of the needs of the building owners will clearly show that roof coatings and cements are necessary supplements to the roofing sheet systems.

Roof coatings are also used as waterproofing mastics on porous walls of buildings, above and below ground - on surfaces such as concrete block, poured concrete and brick. There are a number of types of roof coatings. By far the largest segment of this business is in coatings consisting of asphalt liquified with solvents and bodied with asbestos fibre. Once the asphalt is liquified with solvents sufficiently so that it can be readily applied to the surface without heating, the asbestos fibre is the vital ingredient for several reasons. Without the asbestos, the liquified asphalt will penetrate entirely into the surface it is supposed to rejuvenate, leaving little or no protective layer on top of the surface. On the type of surfaces where there is no penetration, such as on metal, if there is a slope to the roof, the liquified asphalt will sag or run in the absence of asbestos fibre. In addition, the asbestos serves to reinforce the asphalt. After the solvents have evaporated, the asbestos fibre prevents the asphalt from cracking as the surface moves with expansion and contraction from temperature changes. A roof goes through large temperature cycles in every 24 hour period. The asbestos fibre also retards the oxidation and deterioration of the asphalt. This deterioration results from severe exposure to the actinic rays of the sun that is typical for roofs. Last but not least, in the event of fire, the asbestos fibre will retard melting and running of the roof coating.

So far no single raw material has been found that will replace the functions performed by asbestos fibre in solvent thinned asphalt roof coatings. There is a variety of other types of roof coatings sold. Their total volume is far less than the asphalt solvent coatings, so far as asbestos is used, are at least to a degree similar to those described for the asphalt solvent coatings.

As mentioned earlier, large quantities of roof cements are used in addition to the coatings. As already mentioned, almost without exception, no matter how a roof is originally constructed or later repaired, these trowel consistency cements are utilized in that construction and repair. These cements commonly are solvent thinned asphalt or coal tar bodied into a heavy consistency with asbestos and other mineral fillers.

To date no raw material has been found to equal the properties of asbestos fibre in achieving the needed body. To perform their function these cements must be suitable for troweling and at the same time must contain enough bitumen after evaporation of the solvents to deposit a thick film on the roof surface that has good weathering integrity.

The industry has had a strong incentive to find a way to manufacture roof coatings and roof cements without asbestos fibre. Consequently a tremendous amount of work has been done. One aspect of this incentive has been the tightening regulations by EPA and OSHA and the threat of regulations that would make it impractical to continue to use asbestos. Another incentive has been pressure from customers who prefer not to sell or use products that contain asbestos because of the large volume of bad publicity surrounding it. The greatest incentive, however, that the industry has had to formulate around asbestos is the recurring disruptions in asbestos supply that we have experienced in recent years. Over the last 5 years our purchasing staff has spent more time fighting to get enough asbestos to keep our plants running than any other single raw material. We have vowed to get away from the use of asbestos because we cannot afford to be as dependent upon a raw material as we are on asbestos, when it seems every other year or so there is a critical shortage.

In spite of the tremendous amount of work that has been done to try to find a substitute raw material that will produce satisfactory roof coatings and roof cements, to the best of our knowledge no one has found such a material. As the result of our company's vast research, by complicated formulating techniques, utilizing a variety of ingredients and techniques, we are now able to produce solvent base asphalt roof coatings and roof cements that do an adequate job without asbestos fibre. We assume that there are some other manufacturers in a similar position. We do not yet offer these asbestos free roof coatings and cements for sale in the United States because they are about 15 percent more expensive to produce and we believe they are not as good as comparable products made with asbestos. It is difficult to justify selling an inferior product for more money. We are shipping considerable quantities of asbestos free coatings and cements to Sweden, where the use of asbestos fibre in such products has been banned. Therefore, we are gaining experience in the volume manufacture of such products and have the opportunity to observe their performance in large scale use.

We feel strongly that a ban in our country on the use of asbestos fibre in roof coatings and cements would be profitable to our company because we could furnish our customers workable products whereas most of our competitors could not. At the same time, we feel that such a ban would be a great disservice to the American public. In view of the stringent OSHA requirements for handling of asbestos fibre in the manufacture, and EPA requirements for disposing of wastes, no one is being injured by the use of asbestos in our plants. Once the asbestos is bound in the roof coating and cement vehicles, it can do no harm to anyone. Therefore, a ban would not benefit anyone. On the other hand, it would force on the American public a flood of very poor products at high prices.

Let me explain why it has not been possible to make roof coatings and cements of equal quality with substitute raw materials. Asbestos fibre is unique among known raw materials in that it is a completely inert, indestructible mineral that can be processed into a fibre. This fibre partially absorbs the vehicle into which it is placed and becomes an integral part of that vehicle, without settling or floating. Small amounts of asbestos fibre add a large degree of body to the vehicle, so that relatively small amounts of asbestos turn a thin liquid into a consistency akin to apple-butter. What other inert inorganic fibres are there? Very few. Glass is completely unabsorptive. Therefore it is not possible to make a homogeneous coating out of a vehicle with glass fibre. Glass fibre floats in roof coating vehicles, unless it is held down with something else. As a matter of fact, we make some glass fibre roof coatings and cements and we hold down the glass with asbestos fibre. There is a rock wool. In our experience it does not have the absorption properties that will permit a homogenous mixture. Fibrous talcs, wollastonites, ceramics and clays are not fibrous enough to duplicate the performance of asbestos. Most other fibres that are available are organic in nature. They melt, they deteriorate on ageing and most have poor chemical resistance.

Although we do not know of a fibre that can be satisfactorily substituted for asbestos in the manufacture of roof coatings and roof cements, nothing is impossible. We consider it unlikely however that such a fibre will be found in the foreseeable future. The only method we know for manufacturing reasonably satisfactory asbestos free roof coatings and roof cements is to combine some less than satisfactory substitute fibres with a variety of mineral fillers, wetting agents, plasticizers and synthetic thixotropes. We manufacture about 250 different roof coatings, cements and mastics. A variety of techniques must be used to achieve acceptable results in each of these products. The end result in every case is a product that contains considerably less asphalt, tar or other water proofing oil and much more filler material than when asbestos is used. These fillers contribute nothing to the waterproofing properties or weathering of the products. To the contrary, these filler materials often detract from the desirable properties. These formulas require from 30 to 70 percent more energy in our plants to manufacture.

There are Federal Specifications covering asphalt roof coatings and roof cements. Although we have developed asbestos free formulas which we feel are of acceptable quality, they do not meet the standards in the Federal Specifications. In every case the asbestos free formulas exceed the maximum filler content permitted by these specifications. The writers of these specifications rightfully specify a minimum ash content for the fillers that are used. These we are also unable to meet with our asbestos free formulas. At the present state of the art, the General Services Administration would have to lower its purchasing standards for asphalt roof coatings and cements, as would the non-government buyer, in order to utilize asbestos free products.

I need to explain to you my statement that if the use of asbestos fibre in roof coatings and cements was banned, the market would be flooded with very poor products, so poor as a matter of fact that they would be virtually useless. Our company currently ships over twenty million gallons of roof coatings per year. We believe we are the largest manufacturer of roof coatings in the world. Most of our competitors ship two to five million gallons. These competitors cannot afford the research we have spent on developing asbestos free formulas or the dollars that we will continue to commit to this project. Relatively few of our competitors in the roof coating business even have laboratories. In any typical asbestos free formula, there is no one raw material that represents sufficient volume so that it is really worthwhile for raw material suppliers to do adequate research. Raw material suppliers have touted numerous suggested asbestos free formulas, none of which will make a satisfactory product. During recurring periods of asbestos fibre shortages we have seen examples of the type of products that some of our competitors have shipped in desperation. Their only choice was to close their doors because they could not get asbestos or ship the best they could make without. What they shipped was a disaster. These events bring us to the strong belief that should there be an asbestos ban, in order to stay in business, the numerous small competitors will be forced to ship products that are a disservice to the industry and the user.

Another aspect needs to be considered. The hazards of asbestos fibre have been thoroughly researched and documented. They are real but readily controllable and limited. We know little or nothing about the hazards of the variety of raw materials we use in order to manufacture asbestos free roof coatings and cements. We get material safety data sheets from our suppliers. None of the new raw materials are known carcinogens. It is unlikely, however, that anywhere near the amount of research into the health hazards of these materials has been devoted as has been to asbestos. You will, during this workshop, get a health report on only some of the alternate materials that may be used in asbestos free coatings.

The supply picture of the combination of materials needed to make asbestos free coatings must also be taken into account. Several of the raw materials are highly specialized and produced in small volumes. We have determined on some of the materials that the supply is far short of what we would need if our company converted its entire production to asbestos free coatings and cements. We have not investigated whether it is possible to expand the supply in every case to that which would be needed to cover the entire industry. I would assume that given time and sufficient demand a way can be found to supply the needs of the industry with these materials. However, if there should be a sudden ban on the use of asbestos fibre in roof coatings and cements, the available raw material supply would not meet the demand from our company, to say nothing of meeting the industry's demand should other manufacturers want to use the same methods.

TO SUMMARIZE

1. There are a number of types of roof coatings and roof cements.
2. The predominant type that is sold is solvent base asphalt roof coating and roof cement.
3. We do not know of _a_ substitute for asbestos fibre in these products nor in any other type of roof coating.
4. We can make asbestos free solvent base roof coatings and cements by complicated formulating techniques.
5. We believe our company would benefit from a ban on asbestos in roof coatings and cements.
6. Such asbestos free products are more expensive than those containing asbestos fibre and we believe inferior in quality. They do not meet existing Federal Specifications.
7. I do not foresee a change in this picture in the foreseeable future.
8. Little is known about the health hazards of some of the raw materials we would use in order to produce asbestos free coatings and cements.
9. The supply of some of the raw materials we would use is inadequate to meet our company's requirements to say nothing of industry needs.
10. If asbestos were banned in roof coatings and roof cements, in my opinion, the market would be flooded with products so inferior in quality that they cannot perform the purpose for which they are intended.

DISCUSSION ON SEALANTS

QUESTION (Chairman Guimond): I have a question for Mr. Wormser. You mentioned the Federal specifications that require, I think you have indicated it was ash content. Someone yesterday mentioned to me that a certain Federal specification, SSC-153-C, actually specifies required amounts of asbestos.

ANSWER (Mr. Wormser): That is correct. That specification actually specifies asbestos.

QUESTION (Chairman Guimond): Is that frequent in specifications to actually specify that you must have X percent of asbestos or it must contain asbestos or contain certain other materials as opposed to a specific performance?

ANSWER (Mr. Wormser): I think there are other specifications that do specify asbestos. Possibly Dr. Brzozowski is more familiar with the details of the specifications.

ANSWER (Dr. Brzozowski): I could not give you the exact number, but many of the Federal specifications for roof coatings require asbestos in the material.

QUESTION (Chairman Guimond): As a consequence, I would gather that to be a very strong hindrance at the present time for you to be able to sell roof coatings not containing asbestos to the Federal government?

ANSWER (Mr. Wormser): I would say until the Federal government changes their specifications we would not be able to provide them with roof coatings and roof cements.

REMARK (Mr. Hughes): I have a comment that is prompted by Mr. Wormser's observation about the effects of recurring shortages of fiber. I think this is one of the often unrecognized forces that asbestos regulation is imposing on the industry. The fact is that there has been no investment in new asbestos fiber production capacities except in the Soviet Union. The reason is simply because of the very hostile regulatory actitude that prevails in the United States and in some other countries. It is very difficult to justify investment and yet we see these recurring shortages. It imposes substantial costs on the consuming industry and it is a direct result of regulatory actions.

GLASS FIBER REINFORCED CEMENT

by

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and

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ABSTRACT

The paper will present physical properties and characteristics of glass fiber reinforced cement (GRC) and how these are affected by different composite formulations. In addition, it will discuss the various processes for manufacturing GRC and how these affect the characteristics of GRC. A comparison with asbestos-cement and other possible substitutes will be made throughout the paper. Both the economics of GRC versus asbestos-cement and several applications where GRC has been adopted as a substitute will be discussed.

INTRODUCTION

Glassfiber reinforced cement (GRC) is basically a composite of a hydraulic binder, such as portland cement, reinforced with glass fibers, with or without fillers or additives. In this respect it is similar to asbestos-cement with glassfibers as the reinforcing agent instead of asbestos fibers. Like asbestos-cement, GRC is not just one material but is a whole spectrum of composites each with different performance characteristics depending on factors such as the type of cement used, glassfiber content, type and quantity of filler and/or additive, and the density of the composite.

Although GRC has many possible formulations, the predominant basic composite is based on portland cement with an inert filler such as sand or limestone fines and reinforced with a special alkali resistant glassfiber. Much of this paper discusses this particular type of GRC and it will be referred to as high density GRC.

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*Presented by Mr. John Jones.

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PROPERTIES

Figure 1 gives the basic physical properties of GRC containing 5 percent by weight alkali resistant glassfiber. These are compared with manufacturers' data for asbestos-cement.

GRC has properties similar to those of asbestos-cement with one notable exception: impact strength, in which GRC is approximately ten times stronger than asbestos-cement.

Although original formulations of GRC lost a significant amount of this high impact strength over a period of a few years under natural weathering conditions, the long term impact strength was still higher than that of asbestos-cement. However, recent improvements in alkali resistant glassfiber have significantly improved long term durability. Figure 2 illustrates the magnitude of this improvement in the retention of the area under the stress-strain curve, a measure of the impact and abuse-resistance of the material.

All GRC formulations will satisfy ASTM 136 as regards non-combustibility and will be rated 0 on all characterisitics measured by ASTM E84. However, high density GRC (like asbestos-cement) can explosively spall when subjected to very rapid temperature rise as experienced under fire conditions.

Some characteristics of GRC can be changed by changing its formulation. Thermal insulation, fire performance, and high temperature performances are three such properties.

The use of perlite (or a similar lightweight filler) can reduce the density by up to 50 per cent. The effect of reducing density on properties such as thermal insulation can be seen in Figure 3. Also, these formulations provide GRC products with excellent fire resistance properties. Figure 4 shows the fire ratings achieved for different thicknesses of sheet with a density of approximately 62 lbs. per cu. ft. During the tests the sheets showed not only excellent fire resistance, but showed no tendency to spall or crack even after the fire test was stopped and the sheet cooled down.

GRC based on portland cement can be formulated to have good fire resistance properties and satisfactory performance at high temperatures for a short period of time. However, these composites do not usually perform well under prolonged exposure at elevated temperatures, unlike asbestos-cement which performs well up to 600°F and in some cases higher. However, recent lab tests and product field trials have shown that GRC based on high alumina cements and reinforced with alkali resistant glassfiber will perform well certainly up to 600°F, and some recent results suggest possibly up to 1000°F.

Although these GRC composites under prolonged exposure at elevated temperature lose some strength and embrittlement is evident, comparative tests against asbestos-cement have showed that high alumina GRC performs in actual service at least as well as asbestos-cement.

Some areas where high alumina GRC has been compared favorably with asbestos-cement are in furnaces and ovens, and in high temperature electrical equipment.

FIGURE 1

Physical and Thermal Properties
of
Asbestos-Cement Board
and
High Density Glassfiber Reinforced Cement Board

	*ACB	GRC
Dry Density, lbs. per cu. ft.	100	123 to 128
Moisture Content (% of Dry Weight)	5 to 13	2 to 8
Water Absorption (% of Dry Weight)	22 (48 hrs.)	5-10 (24 hrs.)
Modulus of Elasticity psi x 10^6	1.5	2.4
Compressive Strength, psi	12,000	10,000 - 16,000
Tensile Strength, psi	1,400	1,600 - 2,200
Transverse Strength, psi	4,000	3,300 - 4,000
Shear Strength, psi	3,500	5,300 - 7,200
Brinnell Hardness	25	29
Thermal Expansion, In/In/°F x 10^{-6}	5.0	1.3 to 7
Dimensional Change Due to Moisture, In/In		
Shrinkage (Normal to Dry)	0.0020	0.0014
Expansion (Normal to 90% RLF)	0.0006	0.0004
Expansion (Normal to Saturated)	0.0028	0.0015
Maximum Service Temperature, °F	600	600
Surface Burning, ASTM E-84	0-0-0	0-0-0
Permeance, Perms	12	Less than 2
Freeze-Thaw Resistance	Satisfactory	Satisfactory
Thermal Conductivity, BTU/In/Sq.Ft./Hr/°F	4	5
Impact (Falling Ball), Energy Absorption, ft. lbs.	18	229

*The data for ACB are taken from the literature of ACB suppliers.

FIGURE 2

Flexural Stress-Strain After the
Equivalent of 30 Years Weathering

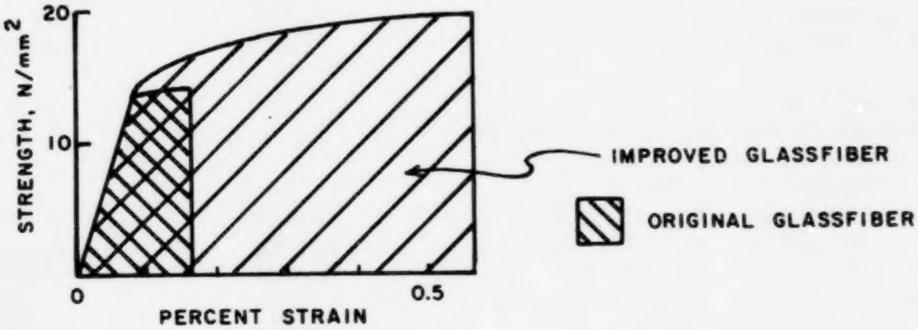

FIGURE 3

Comparative Properties
of
Low and High Density GRC Sheet

Density, lbs. per cu. ft.	125	62
Modulus of Rupture, psi	4000	2000
Water Absorption (Max. % of Dry Wt.)	16	22
Thermal Conductivity (BTU/In./Ft.^{2}/Hr./^{0}F	5.0	2.0
Maximum Service Temperature, ^{0}F	600	600

FIGURE 4

Results of Fire Tests
Conducted on Low Density GRC

Thickness, In.	Unit Weight, pcf	Relative Humidity Per Cent	Fire Endurance*, hr:min
0.688	**	38	0:18
1.181	78.4	72	0.58
3.076	73.6	73	5.35

*Determined by the ASTM E119-79 criteria for temperature rise of the unexposed surface.

**Not weighed.

Although GRC can often offer comparable performance to asbestos-cement, it is not an exact replacement. For instance, the physical appearance of GRC sheet is not yet as good as asbestos-cement in either surface smoothness or thickness uniformity (process developments in progress are expected to correct this). GRC sheet, although it cuts as easily as asbestos-cement, does not fabricate as neatly in that there is more chipping and break-out around the cut edge.

MANUFACTURE OF GRC

The primary process that has been developed for GRC manufacture is based upon a spray concept in which the cement slurry is pumped to a nozzle through which it is atomized into a spray cone. Simultaneously glassfiber roving is chopped, usually to a length from 1 to 2 inches, and the chopped strands are blown into the cement slurry spray.

In small to medium scale production the spray-gun can be held by an operator, but more commonly it is mounted on a simple traverse mechanism which reciprocates back and forth. The spray is deposited either into a mold or onto a dewatering table (the purpose of dewatering is to extract the excess water and compact the sheet).

Such a spray dewatering machine is used by Cem-FIL Corporation (Nashville, Tennessee) for flat and corrugated sheet manufacture. Where much higher volumes are required, equipment has been developed that can produce several million square feet per year. GRC Products, Inc. (Schertz, Texas) is commercially operating such a facility.

Progress has been made in developing techniques to manufacture GRC sheet on the Hatschek process that is used for asbestos-cement production. GRC sheet made by this method has a modulus of rupture of about half that of asbestos-cement sheet, but has been used successfully as a substitute in several applications.

ECONOMICS

The manufacturing cost of GRC is quite dependent on the scale of manufacture. GRC sheets made on the medium volume process described above are about two to two and a half times the price of asbestos-cement sheet. Where the high volume process or the Hatschek process is operated, GRC costs are around 50 percent higher than asbestos-cement. When GRC manufacture becomes more comparable with the scale of asbestos-cement manufacture, the price differential could well be reduced to 20 percent or less.

At the moment, 1/4 inch thick GRC sheet is available at about 80¢ per sq. ft. compared to asbestos-cement which is around 50¢ per sq. ft.

GRC PRODUCTS AVAILABLE

A wide range of GRC products are now commercially available or are in an advanced stage of development.

A full range of flat sheets from 1/8 inch through to 4 inch thick is available from inventory in 4 ft. by 8 ft. sheets. Standard 4 ft. by 10 ft. sheets are available in thinner sheets between 1/8 inch and 3/8 inch. Corrugated sheets in the standard 4.2 inch pitch are also available.

Where high temperature performance or fire protection is required, two grades of flat sheet are in the advanced stage of field trials and are available for product performance trials.

APPLICATIONS

Pullman Standard Company has used 1/4 inch thick GRC sheet as the replacement for asbestos-cement sheet in the lining of electrical closets in Amtrak passenger cars. Amtrak also uses GRC sheet for the same purpose. In this use the asbestos-cement provided both fire resistant lining and some thermal insulation so that if a fire were to occur in the closet, the lining would protect the steel stairway from the upper deck for a sufficient time to allow passengers to escape. GRC sheet was the only substitute that offered the same fire resistance performance as asbestos-cement. Although the thermal conductivity of high density GRC is slightly higher than asbestos-cement, it was satisfactory for the purpose.

E. I. Dupont uses both flat GRC sheet and corrugated sheet as replacements for asbestos-cement. The corrugated sheet is used for repair and maintenance of existing asbestos-cement clad buildings, and for new construction. Flat sheet is used for a variety of uses within the plants, particularly fire resistant linings and partitions.

Several manufacturers are testing GRC sheet as fume hood linings and one company has already started to utilize it in their range of hoods. GRC offers the same chemical resistance as asbestos-cement, being resistant to most chemicals except strong inorganic acids.

The heat resistant grade of GRC has been extensively tested by a variety of oven and furnace manufacturers. In particular, several manufacturers of pizza ovens have approved its use as a substitute for shelves and linings.

GRC sheet, both flat and corrugated, has been used on a limited scale in cooling towers. Flat sheet has been substituted for asbestos-cement in cell partitions and fan decking and corrugated sheet has been used for louvers and end-wall and stairwell casings. GRC has demonstrated the same excellent durability and rot resistance as asbestos-cement under the extreme conditions that exist in cooling towers.

GRC has been used in a wide range of building uses, particularly architectural panels. Wide use is now made of GRC in custom-molded claddings and increasing use is being made of flat GRC sheet in spandrel, soffit, and fascia panels.

GRC is being evaluated as a substitute for asbestos-cement in light duty waterfront bulkheading on canals, inlets and estuaries. GRC corrugated sheeting will probably be approved for this use, since load tests and field trails have demonstrated its structural suitability.

CONCLUSIONS

GRC is not a development material, but in fact, has been in use for over 18 years. Although some of the products are going through evaluation trials, the basic material is backed by years of service use as well as by extensive laboratory testing.

Some of the technology for high volume sheet manufacture is new, but products made on such processes are readily available and are being sold and used commercially.

The principal reason that GRC is proving to be the most widely used material as a general substitute for asbestos-cement sheet is that it has the same excellent general properties, such as good mechanical strength, good chemical resistance, rot proofness, fire resistance, heat resistance, and the ability to be simply machined and fabricated.

Although many materials may be superior in any one of these characteristics, only GRC is like asbestos-cement in that it offers an excellent balance of all these features.

Although GRC is at the moment more expensive than asbestos-cement, there is no doubt that with continued and increasing scale of use over the next few years, the price differential will shrink considerably, and quite possibly could disappear completely.

OTHER SUBSTITUTES FOR ASBESTOS-CEMENT SHEET

by

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ABSTRACT

Asbestos-cement sheet is defined in terms of special qualities imparted by asbestos. Market share is discussed for the four basic forms of asbestos-cement sheet: flat sheet, corrugated sheet, siding shingles, and roofing shingles. Both product substitutes and fiber-for-fiber replacements are considered for low temperature and high temperature applications. Substitute products include cement/wood board, mineral insulating boards, aluminum sheet, wood, and brick. Each product alternative is discussed in detail including product manufacture, composition, durability, life, cost, and market trends. A wide variety of substitute products are available for most asbestos-cement sheet applications.

Asbestos-cement (A/C) sheet products have been used for many years in the United States. I will briefly describe the variety of A/C products available, their uses, and special properties. Substitute products suitable for some A/C product applications will be discussed. Included will be comparisons of composition, strength and durability, cost, life expectancies and market trends.

Asbestos-cement sheet products represent about 6 percent of the total amount of asbestos used in the United States annually.[1] Although used mainly in construction applications such as roofing and siding for both industrial and residential buildings, it is also an ingredient in the manufacture of heaters, boilers, vaults and safes, electrical equipment mounting panels, welding shields, and many other products where a noncombustible or heat-resistant sheet is required.

Asbestos has become important as a reinforcing agent due to its availability, price and unique combination of the following properties:

- tensile strength
- flexibility
- resistance to heat
- chemical inertness and
- large aspect ratio.

Asbestos fibers in cement sheet add to the strength, stiffness and toughness of the material, resulting in a product that is rigid; durable; noncombustible; resistant to heat, weather, and attack by corrosive chemicals; and, in addition, stable. A significant feature of A/C sheet is that it possesses sufficient wet strength to enable it to be molded into complex shapes at the end of the production process.[2] As a result, A/C sheet can be found in four basic forms:

- flat sheet
- corrugated sheet
- siding shingles, and
- roofing shingles.

Substitutes are being sought for a wide variety of A/C sheet products. For flat sheet, the applications range from internal and external paneling, decorative paneling, cooling tower fill, fume hoods, and thermal and fire protection walls, to electrical equipment mounting panels. For each of these applications, performance requirements vary and it is to be expected that several different substitute products will be required. Corrugated sheet is used primarily as a construction material where the additional strength afforded by corrugation is of benefit. Siding shingles constitute a single product class with performance requirements expected to vary according to the geographic location of product use. Similar remarks apply to roofing shingles.

Among the properties that may be important for any particular application of A/C sheet, one may consider the following:

- physical strength
- fracture toughness
- high temperature performance
- electrical conductivity
- resistance to moisture
- resistance to freeze/thaw cycle, and
- overall weather resistance.

Of two possible ways of evaluating performance, that is performance specifications or use specifications, we have chosen use specifications. This is consistent with the experience of industrial manufacturers as well as standard setting organizations such as ASTM (The American Society for Testing and Materials). Just as special formulations are employed to achieve optimal performance of A/C products, it is to be expected that special formulations and product development efforts will be required for substitute products. For many if not most of the substitute products to be discussed today, this fine tuning stage has yet to be reached. Results to date show promise but as we heard for friction products, further development effort will be required before economically viable substitutes for all A/C sheet applications become a reality. Substitutes for A/C sheet include:

- housing materials such as wood shingles, stucco, concrete block, brick, unreinforced cement shingles and asphalt shingles;
- laminated hardboard (Benelex)
- cement/wood board
- polypropylene layered cement sheet
- insulating boards (such as Monolux)
- alumina sheets (Alumina-sheet), and
- glass-reinforced cement sheet, which was discussed by John Jones.

Masonry, galvanized steel, reinforced plastics, and wood can also compete in certain situations. This paper concerns itself mainly with product replacements not fiber replacements.

Brief descriptions of composition and manufacturing methods are provided for seven substitute products. These descriptions are followed by a discussion of limitations of substitute product uses.

Laminated hardboard, such as Benelex, is made from wood. Wood chips are first reduced to fibers by a steam explosion process. The unwanted elements in the wood are driven off, leaving cellulose fibers and lignin, a natural bonding agent. The fiber is refined and then formed into panels. It is currently manufactured by Masonite Corporation of Michigan.[3]

Cement/wood board can be used as an alternative to A/C sheet in some flat sheet applications. It is composed of specially treated wood fibers bound with Portland cement. This board will soon be produced by The International Housing Corporation of California. To make cement/wood board, wood fibers are treated with various chemicals including ammonium chloride, sodium chloride, and sodium silicate in a process called "mineralization" to remove the resins, acids, and sugars present in the wood. These treated fibers are combined with cement to form cement wood board.

Polypropylene cement sheet is manufactured by Conwed Corporation of St. Paul, Minnesota. Details of its manufacture are not available.

Insulating board products such as Monolux are made of calcium silicate cement and selected fillers, reinforced with alkali-resistant glass and wood fibers. Monolux is currently made in England by Cape Boards and Panels, Ltd., and marketed in the United States by W. B. Arnold & Company.[4]

Alumina-Sheet is over 90 percent alumina with about 8 percent silica fibers. Zircar Products, Incorporated, of New York now manufactures this product. It was developed as an asbestos board replacement for certain uses and is suited for a wide range of high temperature, high thermal shock applications.[5,6]

Roof tiles, such as Monray by Monier Company of California, consist mainly of Portland cement, sand, and water. The desired color is sprayed on near the end of the production process.[7]

Roofing shingles such as CeDurShake are made of fiberglass-reinforced polyester resin. They are currently produced by Trim Products of California.[8]

The suitability of substitute products for specific uses is described next. Some products have a narrow range of applications, whereas others such as glass reinforced cement, discussed previously, are suitable for many product applications.

The laminated hardboard product Benelex is used for laboratory table tops, for floors of locomotives and cabooses, and as a phase barrier in electrical switchgear and control apparatus. Laminated hardboards such as this could replace ebonized asbestos in many electrical applications.[3] Benelex is not intended for products requiring resistance to weather or high temperature.

An alternative product such as cement/wood board is claimed to combine the best properties of wood and cement. It is rated noncombustible and is said by some to be virtually impervious to weather. Its modulus of rupture and resistance to impact are greater than A/C sheet and, unlike A/C sheet, it can be glued and laminated. Cement/wood board has good heat and sound insulating properties, is easily machined, and has surfaces suitable for multi-purpose treatment. It also has good elastic properties under a static load. Applications include: external claddings, sound attenuating walls, balcony parapets and floors, walls separating gardens, partitions, noncombustible wall and ceiling linings, roof soffits, refuse shafts, ceilings, fascia, and farm stable linings. It has also been used to build prefabricated houses and pavilions.[9]

Participants at the A/C sheet round table discussion have indicated that at least the cement/wood board products manufactured in Europe during World War II showed poor resistance to weather. They indicated further that cement/wood board is susceptible to excessive expansion due to absorption of water by the wood component during wet weather. It is thus thought by some not to be suitable for exterior cladding. Several means of combatting this tendency to swell cost might thereby be increased. These potential corrective measures include: saturation of the wood component with resin, painting, use of special fasteners to allow expansion of sheet products without fracture, or incorporation of 3-5% mica to reduce expansion.

Polypropylene cement sheet is a type of plastic cement board displaying flexibility and good resistant properties. This product is comparable to A/C sheet in its resistance to freezing, thawing, combustability, and aging. Since it is a type of plastic cement board it is flexible and will not fracture as easily as A/C sheet. It is used for construction of cooling tower spray baffles, buildings, and other large structures.[10]

Monolux is a non-conbustible industrial insulating board which is rigid, non-friable, durable, inert, and resistant to attack by insects and vermin. The board is non-caustic, and unaffected by dilute acids and alkalis, brine, chloride, or volatile solvents. It will not disintegrate, warp, or swell under prolonged immersion in water and is more resistant to heat than A/C sheet. It can be used to make small ovens and dryers, high temperature ducts, oven shelves and interleaves, and as secondary insulation for furnaces and kilns.[4]

The alumina-silica product called Alumina-Sheet also exceeds A/C sheet's resistance to heat. Available in either a moldable or rigid form, it is being used as an insulator in induction core applications, as a molten metal transport trough, and as a material for repairing holes in furnaces. In addition, the possibility of using Alumina-Sheet for laboratory table tops exists. Although not as strong as A/C sheet, its upper temperature limit is several times greater. It is very tough and abrasion resistant.[5,6]

When comparing cost, the products mentioned vary from being quite a bit less expensive than A/C sheet to being 10 times as costly[4-6,9,11,12]. According to a product cost comparison between cement/wood board and A/C sheet done by the cement/wood board manufacturer, the most expensive mill price of cement/wood board is less than half the cost of Johns-Manville Flexboard A/C sheet and less than one-fourth the price of J/M transite A/C sheet. Alumina-Sheet is more than 10 times as expensive as transite, but the price is expected to be cut in half as production increases this year.[5]

Steel is less expensive than A/C sheet and aluminum is competitive.[13] Monier Monray roof tile and CeDurShake roofing shingles cost between $100-$130 for an installed square (a one hundred square foot roof surface), about the same as Supradur A/C shingles.[8,9]

Availability of the substitutes covered here is also a critical factor in their use. Substitute products have already been developed to suit most applications formerly held by A/C sheet. A product such as cement/wood board has been in use in Europe and the Middle East as an all-purpose building board for a number of years.[9] Most others discussed are currently in the marketplace. Unlike other industries now using asbestos which have embarked on a series of research and development programs to find alternative nonasbestos products, the A/C sheet industry has already identified and put into production substitute products with new, nonasbestos formulations which in some cases exhibit better performance characteristics.

In summary, A/C sheet was first used in the early 1900's; substitutes to this product have generally only been developed recently, although, in some applications, materials such as wood and masonry have always been available; newer substitute products are available and appear to function well in place of A/C sheet, but lack the advantage of being time-proven. In general, however, a variety of products incorporating the qualities of A/C sheet at a competitive price are available as substitutes for A/C sheet in many of its present applications. It is expected that further product development work will produce viable substitutes for the remaining applications.

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13. Weston, Roy F., Environmental Consultants, Technological Feasibility and Economic Impact of OSHA Proposed Revision to the Asbestos Standard (Construction Excluded). Asbestos Information Association/North America. March 26, 1976.

DISCUSSION ON SUBSTITUTES FOR ASBESTOS-CEMENT SHEET

QUESTION (Mr. Singe): I have a question for Mr. Jones. I am an architect with the Navy Public Works Center in San Francisco.

Since Johns-Manville apparently has gone out of the AC sheet production, at least on the West Coast, we have been unable to obtain either corrugated or flat sheet. When you say that your product has a standard U.S. corrugation could I conveniently slip it into an existing transite corrugated wall?

ANSWER (Mr. Jones): When I say the standard U.S. corrugation, I mean that the corrugated sheet has been basically produced by the asbestos industry has been 4.2 wave length. In that respect it is the same as the sheet you used. However, before we could decide whether you could just fit it in, we would have to check out the wind loadings to make sure that you had adequate support there. As I said, you cannot necessarily always substitute thickness for thickness. But certainly it is a very easy thing to do. It is a 5- or 10-minute job just to check that out.

QUESTION (Mr. Singe): My second question is, and it is also meant as food for thought for the EPA, in a lot of products like pipe installation, like your corrugated sheet, we have a product that is very similar to the former asbestos-containing product. Our construction workers often cannot tell the difference between a newer product containing no asbestos and the former product containing asbestos, so they treat everything as containing asbestos; thereby, costing us a lot of money, and costing the taxpayer a lot of money because asbestos-containing sheet requires special handling. I would like to see a product like yours, if it is used for replacement of AC sheet, stamped or labeled or somehow coded on the back as containing no asbestos so we know what would require special handling and what does not require special handling.

ANSWER (Mr. Jones): We do this when we send out a pallet of sheet. The shroud that goes on the pallet does have a stamp on it that says it is asbestos-free or contains no asbestos, but it is not actually on each individual sheet.

REMARK (Mr. Singe): Well, this is what we would need.

REMARK (Mr. Jones): It is one we are certainly thinking about. Just on that point, one of the things that we did try in the past was to slightly pigment the sheets to differentiate them form asbestos, but unfortunately we ran into a lot of problems. Some problems were attributed to inconsistency in pigmentation that caused one batch of sheets to be quite a bit different from another batch. Also people who wanted to continue using GRC wanted the product to have the same appearance, so it was somewhat self-defeating and we have since abandoned the approach. But individual labeling of the sheets is probably a good thought.

REMARK (Mr. Speil): I am from Johns-Manville.

First of all I want to congratulate Cem-FIL on a good job in the development of their Cem-FIL glass and the glass fiber reinforced cement products and I want to congratulate Mr. Jones on the way he discussed the fact that you cannot use the numbers that are printed. In other words, modulas of rupture does not mean a thing. What really counts is what strength can you count upon in the material and the strength that you can count upon in the glass-reinforced cement for the long run, is the strength of the matrix.

One point that he did not mention is the fact that alkaline-resistant glass is not alkaline-resistant. It resists alkali better than normal glasses. So you still have a rate of reaction with the cement and that rate of reaction is temperature-dependent. In fact, the rate of reaction increases about twice for every 10 degrees change in temperature. The data that were presented are data in weathering in England, which is relatively mild. In Washington in the last few days I think the rate of reaction would have been about three to four times greater and the life spans that were mentioned would have been thus reduced by that same amount. When you take a look at the 28-day strength data you have to view that with a little bit of trepidation as compared to asbestos cement, which increases in strength with time.

REMARK (Mr. Jones): I would just like to respond to that. The weathering data are not just based on temperate climatic conditions in England. Ever since the start of the project weathering sites have been established around the world and the data have always been taken as an amalgam of test data from all the various weathering sites.

These weathering sites are in places like Nigeria, where you have tropical conditions, and hot desert conditions such as exist in the Middle East. We have weathering sites throughout the United States. We also have various freeze/thaw weathering sites. So, the data are not just based on a temperate climate condition.

I accept the point that, yes, hot, wet conditions are worse than hot, dry conditions, for instance. In hot, dry conditions you get very little change in physical properties; in hot, wet conditions you do. But in addition to the live long-term weathering program, there is also an extensive amount of work being done on hot-wet conditions. By hot, wet I mean hot water over 50°C and we have now an accelerated weathering procedure that will stimulate the worst conditions, which are tropical conditions, and a lot of the data form an amalgam of all these different conditions. It is not just one particular condition.

QUESTION (Mr. Speil): I realize that you have weathering stations all around. Would you give us the length of time that it takes for the strength to decrease in, let us say, Nigeria?

ANSWER (Mr. Jones): Now you are getting a little bit out of my realm. The material always reaches a stable level. It does not continue to fall. That is one thing I should point out. So, we are just talking about the rate at which it reduces to reach the stable condition. The quickest place to reach the stable level has been determined in places like Singapore and Nigeria to be about 2 years. In conditions such as those in England, it is about 4 to 5 years to reach the same level and in the hot desert conditions it can take 10 to 15 years. But I should stress that the stable level is the important level from the point of view of the design considerations and the design velocity we have takes into account the stable level that is reached.

I should also stress that I am talking about the original Cem-FIL fiber on which a lot of the long-term test data is based. For the fiber that was introduced earlier this year, much of the data are simply based on accelerated weathering programs and, to my knowledge, we only have about 2 years of actual data on that fiber. There you are extending the length of time by about a factor of 5 to 10 depending on the particular environmental conditions.

QUESTION (Mr. Speil): Four to five from your own people.

ANSWER (Mr. Jones): Well, it depends on the particular environmental conditions.

QUESTION (Mr. Speil): However, the stable level will be the same: 2,000, approximately?

ANSWER (Mr. Jones): For the original fiber.

QUESTION (Mr. Speil): What is the new fiber?

ANSWER (Mr. Jones): For the new fiber it is about 3,000.

ANSWER (Mr. Speil): It will be 2,000.

REMARK (Mr. Hawley): I am from Marietta Resources.

Getting back to this question of marking nonasbestos products to show that they are asbestos-free, this is in fact being done by two, at least, and possibly three manufacturers of calcium silicate pipe insulation using suzorite mica. The mica is put in a small percentage. It is visible because it is an amber colored flake, a rather large flake, and this is a mark that shows that the product is asbestos-free.

To do this on sheet products you would have to do it on the back layers. I do not know if it would be possible for you to do it with GRC, but I think it would be possible. The advantages of this type of product are that it is inert, it will stand up to any amount of weathering, it does not change color, and it is highly visible for the amount of dollars involved.

REMARK (Mr. Speil): I might add that Johns-Manville is using that mica to mark their calcium silicate insulation and we think it is a very good way of doing it.

SUBSTITUTES FOR ASBESTOS-CEMENT PIPE

by

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ABSTRACT

The Water and Power Resources Service (formerly called Bureau of Reclamation) has installed over 9,600 miles of water conveyance pipelines, ranging in diameter from 4 inches to 21 feet, that have incorporated many types of pipe. Since the first asbestos-cement (A/C) pipe was placed in 1957 on a Service project, over 1,100 miles of asbestos-cement pipe has been installed by this agency.

A/C pipe has proved to be quite competitive -- approximately 80 percent of all pipe that is 24 inches in diameter or less, regardless of pressure class, installed on Service's projects is A/C pipe.

The Service has 13 different types of pipe that it considers for use in construction specifications for water pipelines. Each of these types of pipe are manufactured to Service specifications or have been proof tested to meet Service requirements. The 13 different types of pipe are divided into 2 groups, rigid and flexible. Each group has its own design parameters, pipe trench requirements, and installation practices.

Usually each type of pipe is a composite of two or more different types of material, such as cement, rock aggregate, steel, ductile iron, asbestos, plastics, and fiberglass.

Each type of pipe has its own particular advantage over the other types of pipe or it would cease to be manufactured. These advantages could be: economics, size, pressure range, resistance to certain internal and external environments, strength, and acceptability by the purchaser.

Topics to be discussed include: types of pipe, materials used in manufacturing, design and development of each type of pipe, performance standards, installation practices, and economic comparison.

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*Presented by Mr. James L. Warden

INTRODUCTION

The Water and Power Resources Service, formerly the Bureau of Reclamation, was created in 1902 for the purpose of reclaiming lands and developing water resources in the arid west.

In the period between 1902 and 1940 nearly all irrigated lands were served by open ditches. Only a few pipelines were constructed and those were mainly unlined steel pipes, cast-in-place concrete pipe and some wood staved pipe.

In the period between 1940 and 1955 nearly all irrigation water pipe distribution systems were low head, less than 25 feet of head (11 $lb/in.^2$). The pipe used was unreinforced concrete pipe with mortared joints. Most of these systems have been replaced, but some are giving satisfactory service.

In the mid-fifties the rubber gasket pipe joint became available to all pipe manufacturers, and this revolutionized the pipe industry. Pipe could be laid much more rapidly and efficiently. The rubber gasket created a flexible, watertight joint; hence, there was an increase in confidence in underground pipe systems.

New types of pipe were being designed for higher pressures and new materials were being used to make pipe; therefore, with all the competition between the pipe manufacturers the costs lowered so that pipe was very, very competitive to the smaller capacity open irrigation canals. So competitive, in fact, that the Service designs and builds very few open lateral distribution systems today.

The Service has 13 different types of pipe that it considers for use in construction specifications for water pipelines. Each of these types of pipe is manufactured to Service specifications or has been proof tested to meet Service requirements. The 13 different types of pipe are divided into two groups, rigid and flexible. Each group has its own design parameters, pipe trench requirements, and installation practices.

Usually each type of pipe is a composite of two or more different types of materials, such as cement, rock aggregate, steel, ductile iron, asbestos, plastics, and fiberglass.

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THE SERVICE'S EXPERIENCE WITH ASBESTOS-CEMENT PIPE

Over 9,600 miles of pipelines, ranging in diameter from 4 inches to 21 feet, of various types of pipe have been installed on the Service's projects, which include some of the largest pipe distribution systems for irrigation water in the world--Westlands Water District and the Navajo Indian Irrigation

Project with 670,000 acres and 110,000 acres, respectively. Over 1,100 miles of asbestos-cement pipe have been installed since the first asbestos-cement pipe was installed in 1957. The Service uses an average of 50 miles of asbestos-cement pipe per year, with a maximum of 130 miles installed in 1973.

Asbestos-cement pipe has proved to be quite competitive--approximately 80 percent of all the pipe that is 24 inches in diameter or less, regardless of head, that is now installed on Service's projects is asbestos-cement pipe.

The Service now has had 23 year's of experience with asbestos-cement pipe and we use it with confidence. No asbestos-cement pipeline has ever had to be replaced because of deterioration on a Service project.

DESCRIPTION OF ASBESTOS-CEMENT PIPE - Figure 1

Asbestos-Cement pipe was first manufactured in the early 1900's in Italy, and introduced to the North American Market in 1931. This pipe is a mixture of portland cement and asbestos fibers.

In the manufacturing process, controlled amounts of these materials are blended with water. The slurry that is formed is transferred under pressure onto a mandrel. The mandrel is removed when the pipe is partially cured. An intermediate curing is followed by autoclaving (steam curing for 10 hours at 180°F). In Europe and Mexico water cure is used in lieu of autoclaving. Tests have been conducted proving that autoclaving produces a product that is chemically more stable than water curing, making the autoclaved asbestos-cement pipe much more resistant to sulfate attack and more resistant to soft water deterioration because most of the free lime in the cement has been hydrated.

Only three companies manufacture asbestos-cement pipe in this country. Two companies make it in sizes ranging from 4 inches to 24 inches in diameter and one company makes it in sizes ranging from 4 inches to 42 inches in diameter. All three companies make two types of asbestos-cement pipe, pressure distribution or "Class" pipe and Transmission pipe. The "Class" pipe is made in three classes 100, 150, 200 psi and the transmission in nine classes covering a range of pressure from 25 feet (11 lb/in.^{2}) to 800 feet (346 lb/in.^{2}) of head. The class pipe has much greater safety factors than does the transmission pipe and is not as competitive pricewise.

SERVICE DESIGN OF ASBESTOS-CEMENT PIPE

The Service has its own pipe design standards for most of the pipe that it uses as alternatives in its specifications. The Service designs for asbestos-cement pipe were developed in conjunction with the asbestos-cement pipe industry and the ASTM (The American Society for Testing and Materials) C-17 Committee. The Service's standards are very similar to ASTM's Standard Specifications for Asbestos-Cement Transmission Pipe No. C668, except the Service includes a selection table. These designs are based upon the combined loading theory, developed by the late Professor W. J. Schlick of Iowa State College. The parabola in Figure 2 represents the relationship at the point of breaking between internal pressure and external load under three edge bearing.

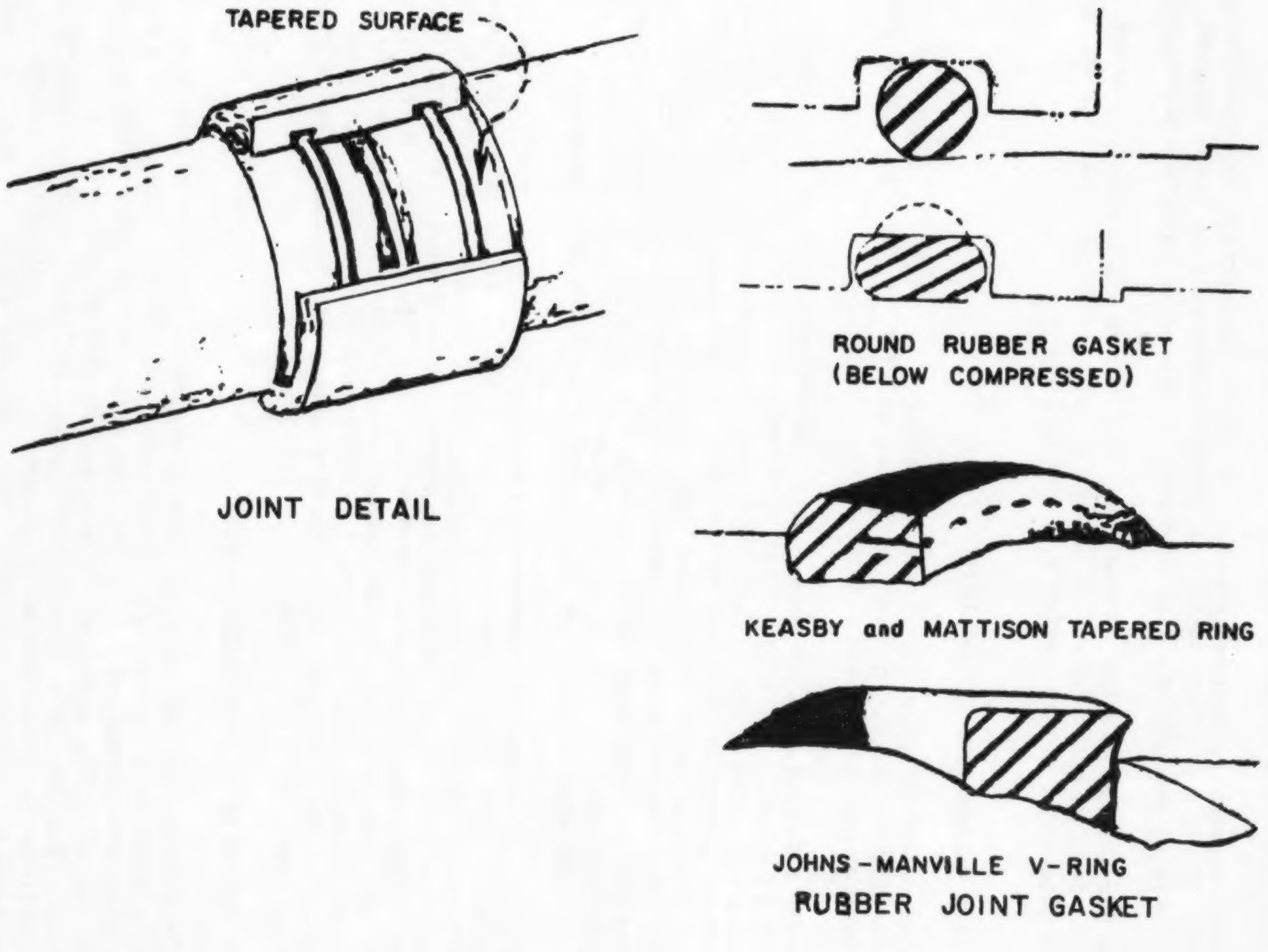

TAPERED SURFACE
JOINT DETAIL
ROUND RUBBER GASKET
(BELOW COMPRESSED)
KEASBY and MATTISON TAPERED RING
JOHNS-MANVILLE V-RING
RUBBER JOINT GASKET

Figure 1. Asbestos-cement pipe.

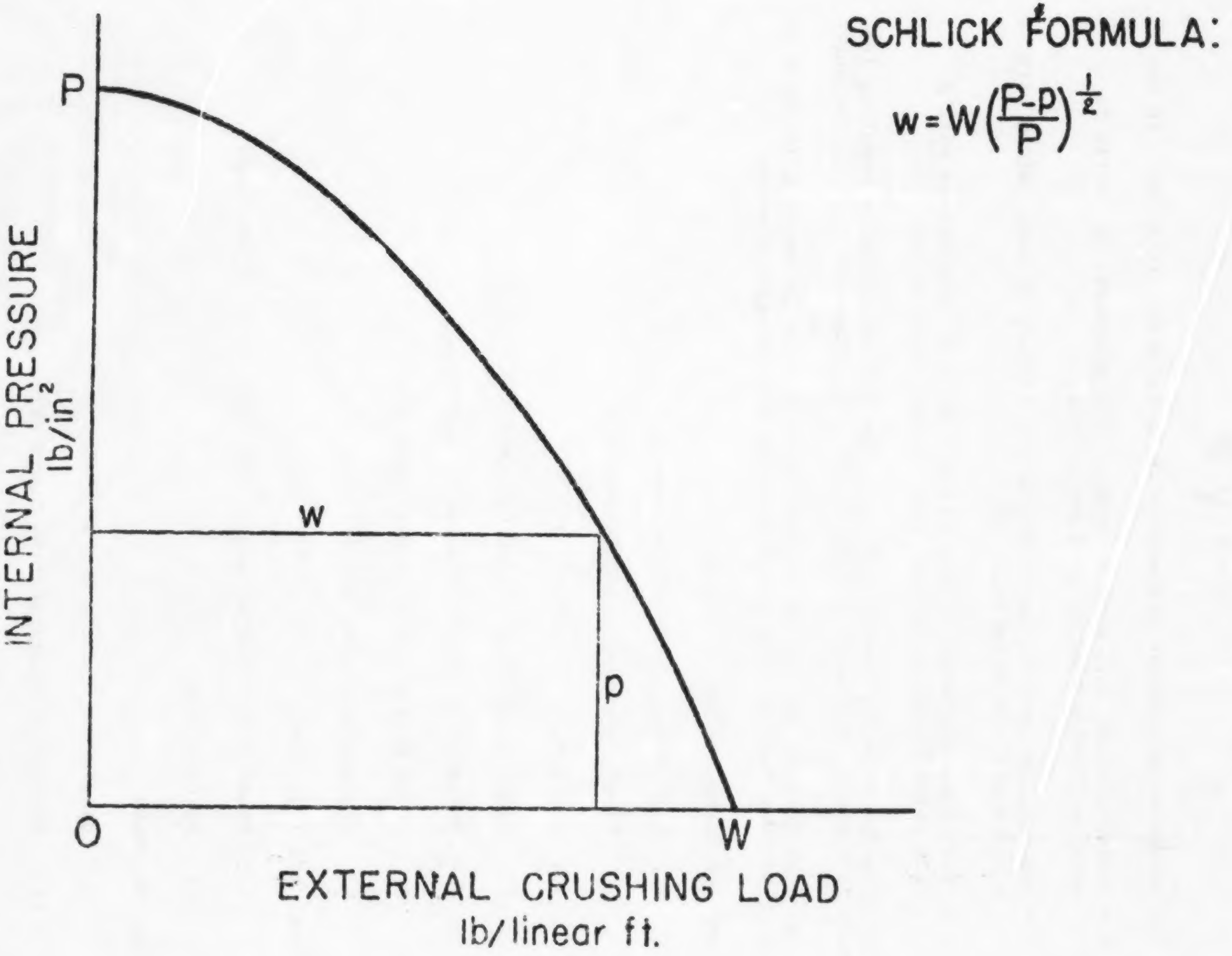


Figure 2. Asbestos-cement pipe design.

The equation (Schlick's formula) for this load/pressure parabola is expressed as:

$$w = W \sqrt{\frac{P-p}{P}}$$

where P = ultimate hydrostatic pressure with no external crush load, in psi.

W = ultimate crush load with no hydrostatic pressure, in lb/lin ft equal to 3-edge bearing load equivalent.

p = hydrostatic pressure including safety factor, in combination with w which will cause failure, psi.

w = crush load including safety factor, which in combination with p will cause failure, lb/lin ft in 3-edge bearing test.

Once the unloaded bursting pressure of the pipe and the ultimate crushing load have been determined, combined loading theory determines the rest of the curve.

Listed as follows are the other pipe options that the Service included in its specifications for pipeline conveyance and distribution systems:

Concrete Pressure Pipes - Figure 3

1. Reinforced Concrete (Bar pipe)
2. Reinforced Concrete Cylinder Pipe
3. Monolithic
4. Noncylinder Prestressed Concrete
5. Embedded Cylinder Prestressed Concrete
6. Lined Cylinder Prestressed Concrete
7. Pretensioned Concrete Cylinder

Steel and Iron Pipes

8. Steel pipe - Mortar lined - Various types of coatings
9. Ductile Iron

Plastic Pipes

10. Reinforced Plastic Mortar (RPM)
11. Reinforced Thermosetting Resin (RTR)
12. Poly Vinyl Chloride (PVC)

TYPE OF PIPE	STEEL CYL.	NON-CYL.	MILD REINFORCING BAR	HIGH STRENGTH WIRE	DESIGN BASIS
Reinforced Concrete (Bar Pipe)		×	×		Rigid
Reinforced Concrete Cylinder Pipe	×		×		Rigid
Non-Cylinder Prestressed Concrete		×		× Wrapped on Concrete Core	Rigid
Embedded Cylinder Prestressed Concrete	×			×	Rigid
Lined Cylinder Prestressed Concrete	×			×	Rigid
Pretensioned Concrete Cylinder Pipe (P.T.)	×		×		Rigid Flex.

Figure 3. Types of concrete pressure pipe.

The above listed pipe options cannot all be used as substitutes, because of the manufacturer's size and head class restrictions.

The following is a description of these pipe options, which includes the design and manufacturing parameters of each type of pipe:

REINFORCED CONCRETE PRESSURE PIPE

General

Reinforced concrete pressure pipe is furnished in sizes from 12-inch diameter on up. The largest the Service has installed has been 132-inch diameter (11 feet), but industry has provided up to 216 inches (18 feet) for some powerplant cooling lines. It can be provided in pressure classes up to 150 feet of head (65 lb/in.^{2}) and for burial depths up to 20 feet. As such, it is competitive with A/C pipe only in sizes from 12 to 36 or 39 inches in diameter and low head classes - 150 feet and less.

Joints

Reinforced concrete pressure pipe is normally supplied with integral bell and spigot joints utilizing a rubber gasket to obtain watertightness. A double spigot joint with a steel coupling sleeve can also be furnished. The most common configuration which has been supplied on Service projects incorporates a gasket groove formed in the spigot of the pipe as shown in Figure 4. The Service terms this configuration a "Type R-4" joint.

Manufacture

The two common methods for producing concrete pressure pipe are by vertically casting or centrifugally casting processes. For vertically cast pipe, the concrete is introduced at the top of the form, and vibrators attached to the outside of the forms insure solid dense concrete. In the centrifugally cast process, the forms are spun fast enough to hold the concrete in place by centrifugal force. "Knockers" hitting against the outside of the spinning form provide vibration. Free water in the concrete mix is forced to the inside surface by the centrifugal action where it is blown out one end of the form. As a result, the water-cement ratio of the final concrete mix is quite low, and the initial set time is shortened.

Most concrete pipe producers attempt to get a 1-day turn-around with their forms. To accomplish this, an overnight cure using steam or high temperature moist heat is provided. After the forms are stripped, the curing is continued until the concrete has gained sufficient strength for handling.

Wall thickness of reinforced concrete pipe are generally approximately 1/12 of the diameter of the pipe for the larger sizes and vary down to a 2-inch minimum thickness for the smaller sizes.

Reinforcement is ordinary concrete reinforcing steel usually formed into circular cages. Only one cage is used in 24-inch pipe and smaller, either one or two cages (providing an inner and outer layer of reinforcement) can be

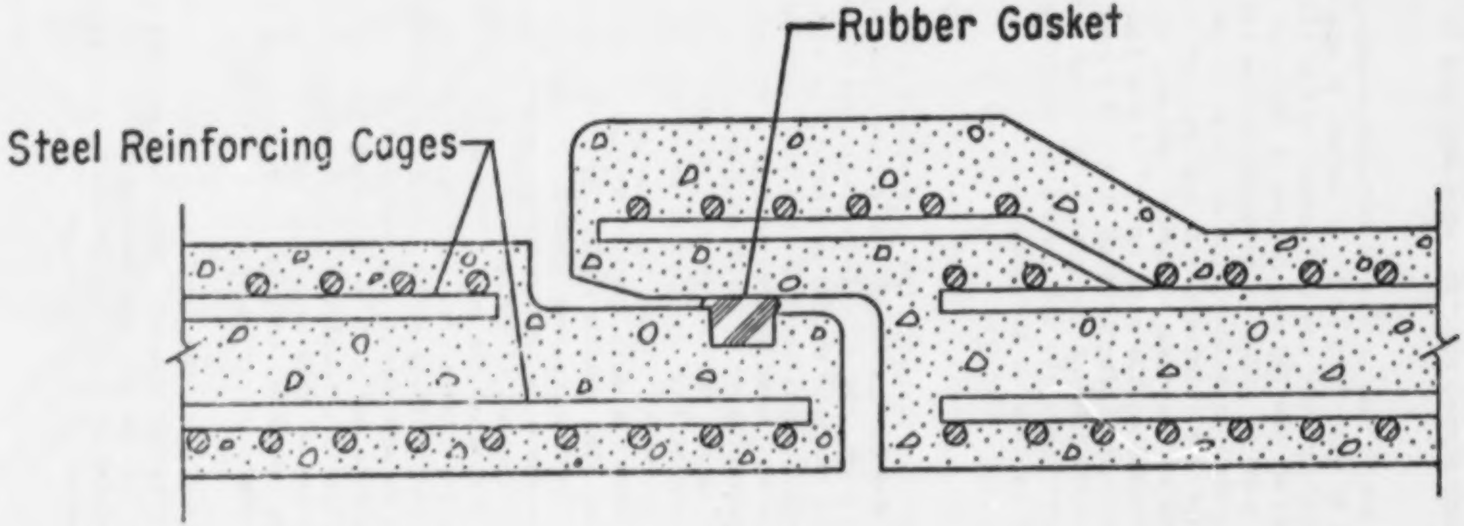

Rubber Gasket
Steel Reinforcing Cages

Figure 4. Reinforced concrete pressure pipe (bar pipe).

used in 27- to 36-inch sizes, and two cages are used in pipe larger than 36-inch diameter.

As an alternative to two layers of reinforcement, one cage formed in an ellipse can be used in pipe from 18 to 72 inches in diameter. With the elliptical shape, the reinforcement can be located within the pipe wall so that it is at the inside face at the top and bottom of the pipe and at the outside face at the sides of the pipe in order to accommodate the tensile stresses resulting from the bending moments which occur at these locations when the pipe is loaded. Use of elliptical reinforcement requires the cage to be accurately oriented in the forms at the time of manufacture and the location of the field top be permanently marked on the pipe unit. At the time of installation, the contractor must then install the pipe so that the field top of the pipe unit is on the vertical centerline of the pipe, with a maximum allowable deviation of 10 degrees from the vertical. Elliptically reinforced pipe just does not work very well if it is laid on its side.

Design

Reinforced concrete pressure pipe is designed as a rigid structural ring which transmits the applied loadings down through the pipe wall into the foundation soil. As such, the pipe is weakest when subjected to a line loading on top and a line reaction on the bottom and is strongest when subjected to a uniform radial loading all around the pipe, such as an external pressure. The installed pipe is subjected to a combination of loadings instead of the idealized loadings just described. The soil above the pipe applies varying loads to the pipe which are assumed to act radially over the top and sides of the pipe, the dead load of the pipe itself are vertical forces acting downward, the weight of the water inside the pipeline applies forces acting radially outward, and hydrostatic pressure inside the pipe results in uniform radial forces acting outward: The reaction force from the supporting foundation soil depends entirely on the construction procedures used at the time of installation. As stated previously, a line reaction is a severe loading condition, and the pipe is much stronger if the reaction can be spread out over a particular area at the bottom of the pipe. The angle at the bottom of the pipe over which the loads are transmitted from the pipe wall down into the foundation soil is termed the "bedding angle," with a zero degree angle representing a line reaction. As an economical compromise, the pipe for Service projects is designed for a bedding angle of 90 degrees. To ensure that this angle is obtained, our specifications require select material to be placed under the haunches of the pipe and up to a height of three-eights of the pipe O.D. This material must be compacted to 95 percent of standard Proctor density in order to provide the necessary support for the pipe.

Analytical studies have been performed to derive the mathematical coefficients by which the internal moments, thrusts, and shears in the concrete pipe wall can be obtained for the various loading conditions. Once these are known, ultimate strength reinforced concrete theory is used to obtain the required wall thickness and amount of reinforcement.

PRETENSIONED CONCRETE CYLINDER PIPE (PT)

General

Pretensioned concrete cylinder pipe is furnished in 10-inch through 54-inch diameters, pressure classes up to 700 feet of head (300 lb/in.^{2}), and for burial depths up to 20 feet. It is very competitive with A/C pipe in sizes larger than 24 inches and in the higher pressure classes.

Joints

PT pipe utilizes what the Service terms an "R-2" type of joint. This joint incorporates a rubber gasket contained in a formed groove in a steel spigot ring. See Figure 5. The rolled steel shape from which the spigot ring is formed is termed a "Carnegie" shape. The steel bell ring is a rolled flat plate properly sized to mate with the spigot ring. Tolerances in this type of joint are extremely close with the difference in the circumferences of the outside of the spigot ring and the inside of the bell ring being less than 3/16 inch. Nevertheless, with the smooth steel surfaces in the joint, there is little or no tendency for the gasket to fishmouth, and there are very few construction problems associated with this type of pipe.

Manufacture

Forming the steel cylinder is the first step in the manufacture of PT pipe. This is normally done by rolling a continuous sheet of flat steel plate into a helix and automatically butt welding the edges together. The resulting helically welded cylinder is then cut to the proper length, and the spigot and bell rings are welded on. At this stage, each cylinder is hydrostatically tested at a pressure which stresses the steel to 20,000 lb/in.^{2}. At this pressure any defects in the welds are readily apparent and are repaired by manual welding. After hydrostatic testing, the mortar lining is applied to the inside of the cylinder by centrifugally spinning and either steam or water cured to obtain its design strength. Steel reinforcing rod is then wound around the cylinder under a prestressing tension of 8,000 to 10,000 lb/in.^{2}, and the pipe unit is completed by the application of a mortar coating on the outside of the reinforcing rod.

Design

For design purposes, PT pipe is divided into two categories. Eighteen-inch diameter and smaller pipe is considered to be rigid, and the mathematical coefficients for the moments, thrusts, and shears are used based on a 90-degree bedding angle as for reinforced concrete pipe. Pipe larger than 18 inches is considered flexible and moments and thrusts are determined using beams on elastic foundation theory and considering the pipe to be supported for the full 180 degrees on the bottom. After moments and thrusts are determined, the design proceeds according to ultimate strength theory for reinforced concrete. The steel material for the cylinder and the reinforcing rod wrap is specified so that the cylinder will have a lower yield strength than the rod wrap, and because of the effect of the initial prestressing force, failure of the pipe will occur with the cylinder and rod wrap at their respective yield strengths and the mortar lining at its ultimate compressive strength.

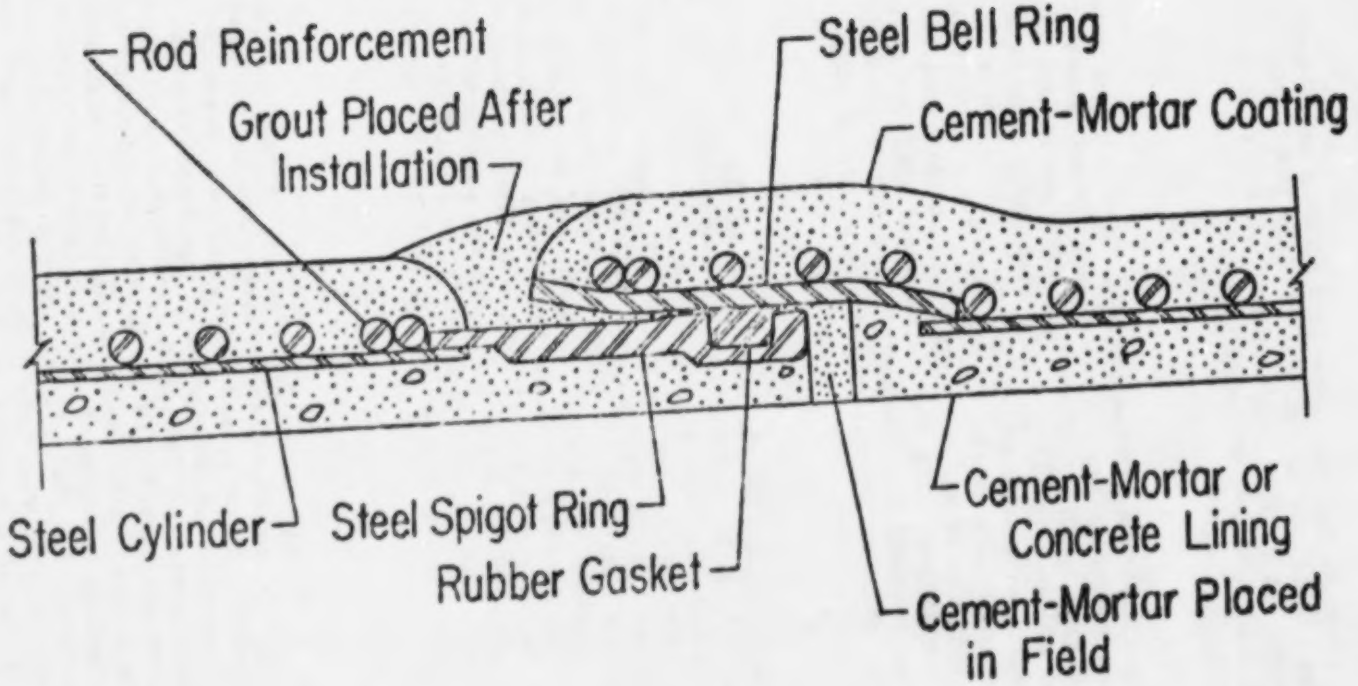

Rod Reinforcement
Grout Placed After Installation
Steel Bell Ring
Cement-Mortar Coating
Steel Cylinder
Steel Spigot Ring
Rubber Gasket
Cement-Mortar or Concrete Lining
Cement-Mortar Placed in Field

Figure 5. Pretensioned concrete cylinder pipe.

To provide the full 180-degree bedding consistent with the beams on elastic foundation assumption, the soil backfill under the haunches of the pipe and at the sides of the pipe up to a depth of 0.7 times the pipe outside diameter is specified to be compacted to 95 percent of Proctor density.

DUCTILE-IRON PIPE

General

Ductile-iron pipe is furnished in diameters from 3 inches through 54 inches and for pressure classes up to 1,000 feet of head (450 lb/in.^2) including transient surge pressures. When installed in a very good trench laying condition, the pipe can withstand burial loads exerted by from 55 to over 100 feet of earth cover, depending on size. Although somewhat more expensive than A/C pipe, some economics can be achieved with ductile-iron pipe by relaxing some of the trench installation requirements.

Being a metal product, ductile-iron pipe is subject to electrolytic corrosion when installed in areas where soil resistivity values are low. In these areas, cathodic protection must be provided which would entail electrically bonding the pipe units together by welding a jumper across each joint. In many instances, providing test stations to monitor the pipeline may be sufficient, but in severe situations an impressed electrical current may be required. Additional corrosion protection is provided by normally installing the pipe with a polyethylene wrap on the outside of the pipe.

Joints

For irrigation and long water supply pipelines, ductile-iron pipe is normally furnished with bell and spigot, rubber gasketed, push-on type joints. Mechanical type rubber gasketed joints and standard flanged joints can also be provided for other applications. In the bell and spigot joint, the gasket is contained in an annular space in the bell and has a special cross sectional shape in order to seal effectively against the smooth spigot end of the pipe.

Manufacture

Cast iron and ductile iron are essentially alloys of iron containing carbon and other chemicals. The primary difference between cast and ductile iron is that in cast iron, the carbon occurs as free carbon or graphite in the form of flakes interspersed throughout the metal. In ductile iron, the carbon is in nodular or spheroidal form and more finely interspersed in the metal. This change in the graphite form is accomplished by adding, at the appropriate moment, a charge of magnesium to the molten iron. The pipe is then centrifugally cast in a spinning mold. When the molten iron has solidified but is still red hot, it is removed from the mold and annealled for an appropriate period of time. When cool, a thin cement mortar lining is applied to the inside of the pipe.

Design

Since ductile iron is a homogenous material, the design of this type of pipe is relatively straightforward and is based on a minimum yield strength in tension of 42,000 lb/in.^{2}. Ductile iron is considered a flexible pipe although in the smaller sizes it has significant ring stiffness which is reflected in the design equations. The equations also consider the lateral support that a flexible pipe receives from the compacted backfill soil at the sides of the pipe when the pipe is deflected under external earth and live loads. Based on the bending stresses due to external loads and tensile stresses due to internal pressure, standard tables have been prepared from which the required minimum wall thickness can be determined for a particular installation. In the determination of the required wall thickness, a design safety factor of two is applied to the tensile yield stress and a design ring bending stress of 48,000 lb/in.^{2} is used which is considered conservative and appropriate. The bending stresses are determined considering a maximum design deflection of 3 percent of the pipe diameter.

REINFORCED PLASTIC MORTAR PIPE (RPM)
REINFORCED THERMOSETTING RESIN PIPE (RTR)

General

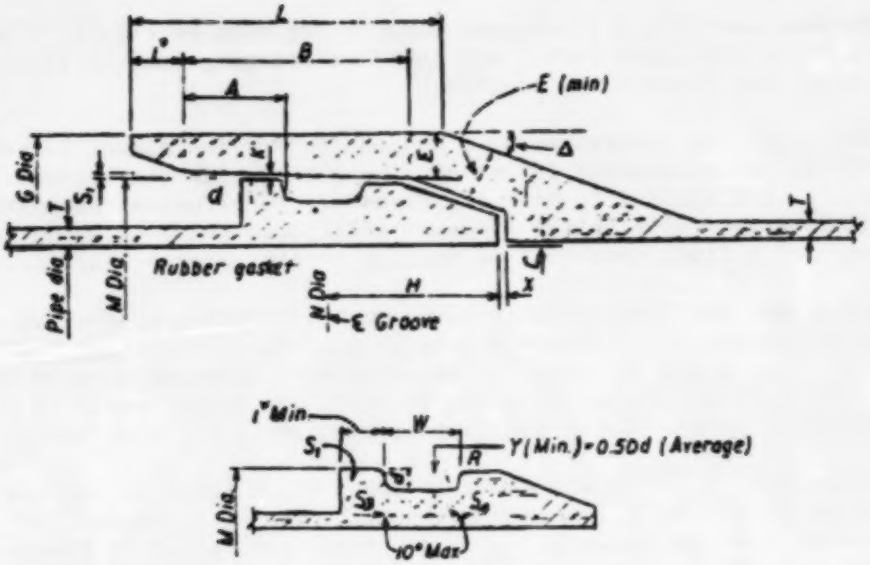
These two types of plastic pipe are composed of fiberglass and polyester plastic resin. In addition, RPM pipe also contains ordinary sand as an inert filler to build up the pipe wall. RTR pipe, also frequently call FRP for fiberglass reinforced plastic, contains only glass and resin. Other types of resins, such as epoxy and vinyl ester, are also used for these types of pipe, but due to their expense, they are seldom utilized for irrigation or water supply pipelines. RPM pipe is furnished in sizes from 8 inches to 54 inches in diameter while RTR pipe can be obtained as small as 1-inch diameter. Although the Service limits the maximum size for these types of pipe to 54 inches, industry has the capability of manufacturing these products up to 144 inches (12 feet) in diameter. Both types can be provided for pressure classes up to 500 feet of head (220 lb/in.^{2}) and for burial depths up to 20 feet. As with PT pipe, these products would be competitive with A/C pipe in sizes larger than 24 inches and in the higher pressure classes.

Joints

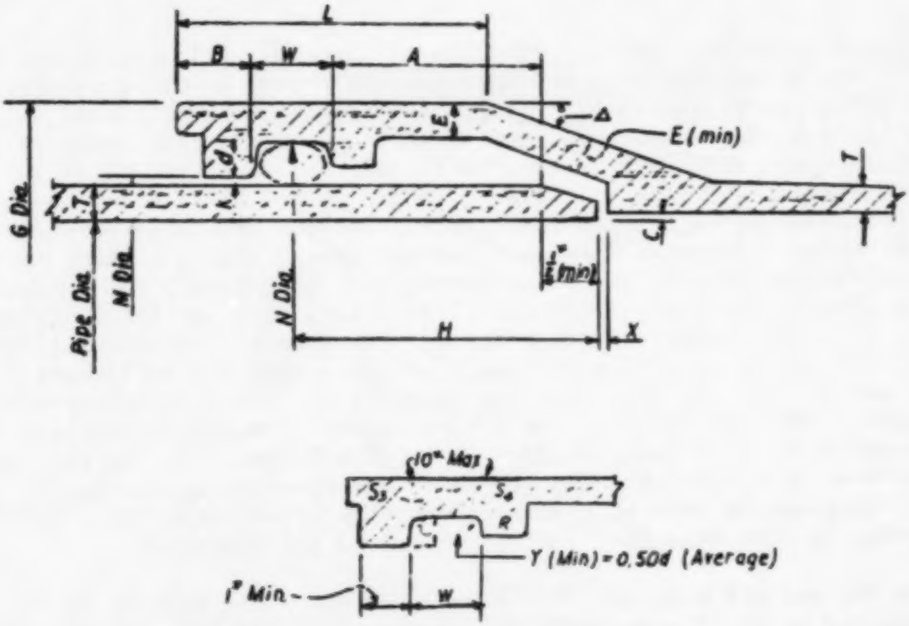
To date, RPM pipe has only been made with an R-4 type joint, that is, with the rubber gasket confined in a groove in the spigot. RTR pipe also is manufactured with R-4 joints but, in addition, can be made with the gasket groove in the bell and can also utilize a separate coupling such as A/C pipe. Figure 6 shows examples of RPM and RTR pipe joints. With smooth plastic surfaces, these joints have little tendency to have fishmouth gaskets; however, liberal use of lubricant during installation is still highly desirable.

Manufacture

Both types of pipe can be manufactured by either a filament winding process or by centrifugally casting. When centrifugally cast, the fiberglass and resin (and sand, in the case of RPM) are introduced into a mold which is spun until the catalyzed resin hardens. The fiberglass can either be woven glass cloth put into the mold while at rest or it can be introduced as short chopped fiber strands about 4 inches long while the mold is spinning. In the filament


L
1"
B
A
E (min)
Δ
E
x
G Dia
S₁
T
d
Pipe dia
M Dia
Rubber gasket
N Dia
H
x
C
℄ Groove
1" Min
W
S₁
Y (Min.) = 0.50d (Average)
R
M Dia
S₃
S₄
10° Max

(a) GASKET GROOVE ON SPIGOT END OF PIPE


L
B
W
A
E
Δ
E (min)
T
d
x
G Dia
T
C
Pipe Dia
M Dia
N Dia
1/4" min
H
X
10° Max
S₃
S₄
R
Y (Min) = 0.50d (Average)
1" Min
W

(b) GASKET GROOVE IN BELL

NOTES Δ Maximum = 20°
An outside diameter of at least G dia shall be maintained, a minimum of L distance from end of bell.

Figure 6. RPM and RTR Pipe Joints.

winding process, continuous fiberglass strands are bundled together, passed through a bath of catalyzed resin, and wound on rotating mandrel which moves longitudinally past the winding station.

For RPM pipe, the fiberglass is wound on the mandrel almost perpendicular to the mandrel, and additional layers of fiberglass, with the strands oriented longitudinally, are applied to give the necessary longitudinal beam strength. Sand is added periodically in the process, additional glass is wound on top of the sand, and a final sand coat is applied to the exterior surface.

For RTR pipe, the fiberglass is wound on the rotating mandrel at an angle of from approximately 57 to approximately 75 degrees with the longitudinal axis of the pipe. This gives the pipe its required beam strength instead of providing longitudinally oriented glass fibers. The actual angle is dependent upon the relative values of the required beam strength and hoop strength.

After winding, both RPM and RTR pipe units are allowed to cure in an oven environment until the resin has completely hardened, after which the pipe unit is removed from the mandrel. With RPM pipe, the spigot is then cast into the prepared end of the pipe by placing the pipe on end in a heated mold into which resin is poured. No fiberglass is included in this operation.

Design

In these types of pipe, all stresses in the pipe wall are considered to be carried by the fiberglass only and that the resin only provides watertightness and that holds the fiberglass in place. A characteristic of plastic pipes such as these is that when subjected to a fairly high stress level which is held constant, the pipe will fail after a particular period of time. If subjected to a lower stress level, it will take a longer period of time for the pipe to fail. This strength regression relationship between stress level and time to failure plots as a straight line on a log-log graph, that is, when log time is plotted versus log stress, and the mathematical relationship can be determined through a statistical analysis of data from a long term laboratory testing program. From this relationship, a design stress level can be established which will result in an estimated time to failure which is sufficiently long so as to ensure that the pipe will not fail for the life of the project. (For a typical RPM compound, if the design stress is taken as one-half of the stress level which will cause failure in 100,000 hours (11.4 years), the estimated time to failure for the design stress level is approximately 28,000 years.) The required area of fiberglass is then established for a particular installation so that this design stress level is not exceeded.

Both RPM and RTR pipe are considered flexible pipes and, as such, require well compacted backfill underneath and at the sides of the pipe to prevent excessive deflection. This backfill should be compacted to 95 percent of Proctor density to a depth of 0.7 times the outside diameter of the pipe.

POLYVINYL CHLORIDE PIPE (PVC)

General

PVC pipe is furnished in sizes up to 18 inches in diameter and as small as 1/8-inch diameter tubing. Some manufacturers are in the process of expanding the range up to 22- or 24-inch diameter, and by this time, some of these larger sizes may be available. PVC irrigation pipe has pressure ratings based on the ratio of the dimensions of the outside diameter of the pipe to its wall thickness so that pipe with the same dimension ratio will have the same pressure carrying capability, regardless of size. Other types of PVC pipe, such as schedule 40, 80, and 120 pipe, having the same dimensions as the corresponding iron pipe, are also available. The pressure ratings of the schedule pipe vary with the pipe diameter, with the smaller pipe being considerably stronger than the larger pipe. With the standard dimension ratios, irrigation pipe can be obtained with pressure ratings up to 700 feet of head (300 lb/in.^{2}) and for burial depths well over 20 feet.

Joints

PVC irrigation pipe is furnished with either rubber gasketed joints or solvent cemented joints. Because of the reliability and ease of installation of the rubber gasketed joints and because successful solvent welding is highly dependent upon temperature, humidity, blowing dust, and highly qualified workmen, the Service requires rubber gasketed joints for PVC line pipe. The rubber gasketed joints are either of the separate coupling type, similar to A/C pipe, or else are bell and spigot with an annular space for the gasket formed in the bell.

Manufacture

Polyvinyl chloride is a thermoplastic resin. That is, it can be repeatedly softened by an increase in temperature and hardened by a decrease in temperature. In the highly automated manufacturing process, the raw resin, in powder form, is fed to an extrusion machine where it is heated under pressure (2,000 to 5,000 lb/in.^{2}) until the resin particles fuze together into a viscous, plastic mass. The material is extruded through a forming die which molds it into a cylindrical shape and then immediately cooled into a solid state by chilled water. Since the operation is continuous, the pipe is automatically cut to length by a moving saw that travels at the same speed as the pipe is being extruded. For bell and spigot type pipe, the bell is then formed by reheating one end of the pipe to a pliable state, forcing it over a forming mandrel, and again cooling it to a solid state.

Design

Thermoplastic compounds, such as PVC, exhibit the same strength regression characteristics as the fiberglass reinforced compounds as described under RPM and RTR pipe. Therefore, the design stress level for PVC pipe is also based on the long term strenth of the product as determined by a laboratory testing program. The required wall thickness can then be established so that the design stress is not exceeded.

PVC pipe is also a flexible pipe and will deflect under external trench loadings. Many of the pipe manufacturers recommend compacted backfill at the sides and up to 1 foot above the top of the pipe, and we require highly compacted material to 6 inches above the pipe. In smaller diameters and with greater wall thickness, however, the pipe does have significant ring stiffness, and the pipe can be designed to carry significant trench loads with little lateral support from the soil at the sides of the pipe. This allows relaxation of the compaction requirements for the backfill soil, resulting in a savings in installation cost.

STEEL PIPE

General

Steel pipe is practically unlimited in size and pressure ratings. The largest steel pipe the Service has installed for water supply purposes is 96 inches in diameter; however, 40-foot-diameter penstocks for dams and power plants can be considered as steel pipe. The service requires steel line pipe to be cement mortar lined on the inside and coated on the outside with either cement mortar or coal tar enamel wrapped with kraft paper. Steel pipe is considerably more expensive than A/C pipe but can be used as a very acceptable substitute.

Joints

Joints in steel pipe are either welded or are bell and spigot type with a gasket groove rolled either in the bell of the pipe or on the spigot end. Figure 7 shows a typical joint with a gasket groove rolled in the spigot. Some manufacturers can furnish a joint incorporating a carnegie shaped spigot ring welded to the steel cylinder. This joint has a big advantage due to the stiffness of the ring; however, it is more expensive and seldom done. Welded joints are normally butt or lap welded after which the mortar lining and appropriate coating are placed in the field.

Manufacture

Steel pipe is manufactured either by helically welding a continuous roll of steel sheet or by forming the cylinder from flat plate and using longitudinal welds. If rubber gasketed joints are being provided, the bell and spigot are rolled to their appropriate shape, and the cylinder is hydrostatically tested.

Many of the designs for steel pipe require very little wall thickness, and the cylinder has a tendency to warp due to the heat of welding. To eliminate this, the hydrostatic pressure inside the cylinder is raised to stress the steel slightly beyond its yield point. This causes the cylinder to round out, and, because the steel has yielded slightly, to retain its circularity when the pressure is reduced. The slight increase in diameter resulting from this operation is taken into account when forming the cylinder initially.

After the cylinder is rounded out, the mortar lining is centrifugally spun on the inside of the pipe and the appropriate coating applied to the outside.

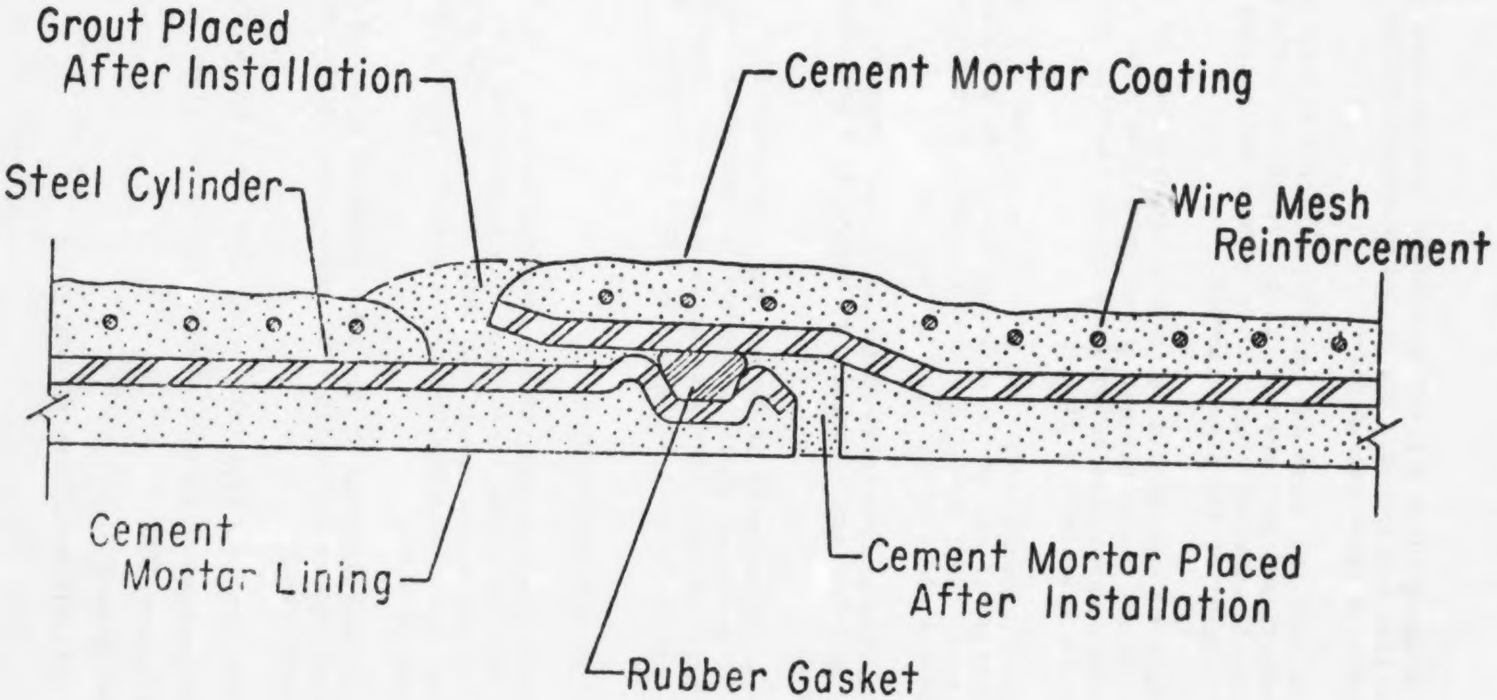

Grout Placed After Installation
Cement Mortar Coating
Steel Cylinder
Wire Mesh Reinforcement
Cement Mortar Lining
Cement Mortar Placed After Installation
Rubber Gasket

Figure 7. Steel pipe (mortar lined and coated).

Design

Steel pipe is designed as a flexible conduit, but its ring strength and arch strength are also considered. The design procedure follows that in AWWA Manual M11 which covers three design cases:

1. When the wall thickness and diameter selected to meet pressure requirements are such that its ring strength is sufficient to carry all external trench loads without deflections greater than 2 percent of the pipe diameter.

2. When the ring strength is sufficient to carry part of the external trench loads, but not all of it without undue deflection. Some side support must be provided by the backfill soil under and at the sides of the pipe.

3. When the ring strength of the pipe is so low that it can carry very little, if any of the external trench loads without undue deflection. Full mobilization of the passive resistance of the soil at the sides of the pipe is required.

Charts and tables are provided in the manual to determine the allowable earth and live loads that can be carried by a pipe of a particular diameter and wall thickness.

Steel pipe on the majority of Service projects would fall into the third design category as described above. In order to ensure the necessary side support for the pipe, we require the backfill soil to be compacted to 95 percent of Proctor density up to a depth of 0.7 times the outside diameter of the pipe.

ADDITIONAL TYPES OF PIPE SUBSTITUTES

The substitute pipes as described in the preceeding portion of the paper are those pipes that have been thoroughly investigated and have been accepted by the Service for use in its specifications. It is not the intent of this paper to represent that these are the only types of pipe available or the only ones that can be used.

Listed as follows are some of the other types of pipes that are presently being manufactured that could possibly be substituted safely and economically for asbestos-cement pipe:

1. Concrete pressure pipe reinforced with steel wires (fibers)
2. Concrete pressure pipe reinforced with fiber glass
3. Polyethylene (PE)
4. Polybutylene (PB)
5. Acrylonitrile Butadiene Styrene (ABS)

It usually takes approximately 5 years of investigations and testing before the Service will use a new type of pipe as an option in its specifications. The purpose of this conservatism is that the Service must be reasonably sure that the pipe will last at least the length of the repayment contract with the water districts, which is usually 50 years.

AGGRESSIVE TRANSPORTED WATERS

Aggressiveness of water transported through Asbestos-Cement Pipe as described by ASTM C500 Standards is as follows:

Highly aggressive	$pH + \log(AH) < 10$
Moderately aggressive	$pH + \log(AH) = 10.0$ to 11.9
Nonaggressive	$pH + \log(AH) \geq 12.0$

where

pH = index of acidity (or alkalinity) of the water, standard pH units

A = total alkalinity, ppm as $CaCO_3$, and

H = calcium hardness, ppm as $CaCO_3$

If the $pH + \log(AH)$ is < 10, the water is highly aggressive and some means must be taken to insure the integrity of asbestos-cement pipe. This also applies to all types of cement mortar lined pipe. Lining of the inside of the pipe with an inert material is one solution. Ductile-iron pipe uses an asphaltic seal coat over its cement mortar lining for protection. Treatment of the water before entering the pipeline is another solution.

ECONOMICAL ADVANTAGES

Asbestos-cement has an economical edge over the other types of pipes, for sizes 6 inches to 24 inches in diameter for the following reasons:

1. It costs less to produce because the method of manufacturing asbestos cement pipe lends itself to automation and the materials used in making the A/C pipe cost less in these diameters.

2. Asbestos-cement is a rigid type of pipe. It takes less work in installation than does the flexible type pipe because almost half as much compaction is required. Cathodic protection is not needed for asbestos-cement pipe.

3. Cathodic monitoring stations are required for all steel, ductile iron, and steel cylinder pipe, which require all joints to be bonded.

4. If the soil resistivity is low, less than 2,000 ohm centimeters, cathodic protection must be included in the cost of steel and steel cylinder and ductile iron pipes.

For diameters greater than 24 inches and heads higher than 200 feet, the other listed substitute pipes compare very favorably or are more economical than asbestos-cement pipe.

SUMMARY

1. The Service has installed an 1,100 miles of asbestos-cement pipe during the past 23 years and none has had to be replaced because of deterioration.

2. Reinforced Concrete, Pretensioned Concrete, Lined Cylinder, Steel, Ductile Iron, Reinforced Plastic Mortar, Reinforced Thermosetting Resin, and Poly Vinyl Chloride pipes can all be competently substituted for asbestos-cement pipe, but are not economical substitutions for pipe diameters of 24 inches and less.

3. New types of pipes are being manufactured that could be substituted for asbestos-cement pipe, but usually it takes about 5 years to investigate and test them before they are accepted by the Service.

4. Asbestos-Cement Pipe and all cement mortar lined pipe should be coated on the inside of pipe with an inert material if waters having an aggressive index of less than 10 are transported through them.

DISCUSSION ON SUBSTITUTES FOR ASBESTOS-CEMENT PIPE

QUESTION (Mr. Levy): You said that you have never had to replace any AC pipe in 23 years of experience. Can you make similar claims for the other materials that you specified and now use?

ANSWER (Mr. Warden): Yes. We have had to replace some reinforced bar pipe where we have had some expansive soils. This was probably our fault because we may have under-designed it. We have had to replace our reinforced concrete pipe and also steel pipe that had rusted out because it did not have cathodic protection. Now we are including cathodic protection on all of our steel and steel cylinder pipes.

REMARK (Mr. Atkinson): I am Deputy Executive Director of the American Waterworks Association.

I would like to file with the Chairman of the working group a paper that was developed by our California/Nevada section with regard to asbestos-cement pipe.

I would also like to say that our association has standards for practically all the pipe that is manufactured in this country, particularly pipe that is used in drinking water.

The Association takes a neutral part on what type is to be used and thinks that should be left up to the user based on the recommendations that he receives from his engineering consultant for the particular project for which the pipe is to be used. We do feel, however, that regulations that might be issued by the Federal government should be based on sound scientific knowledge and not mere conjecture that some particular product or process may have an adverse effect on the health of persons.

I think this is very important because one of the reasons for this workshop, I think, is for EPA and the Consumer Product Safety Commission to try to gather additional information on whether or not they are going to apply certain rules and regulations with regard to the use of asbestos.

QUESTION (Dr. Millette): In the Service you apparently make measurements of the soil resistivity or corrosion problems of the exterior of the pipe. Do you also make measurements of the water quality in terms of corrosion index or other indexes and do those come into your specifications at all?

ANSWER (Mr. Warden): We actually do make measurements of the different types of water and the conditions that the pipe is going to be laid in. In fact, in the West we have a very high sulfate content where we lay our pipe and in our concrete structures we require Type 5 cement and we do take readings to determine what type of soil our pipelines are going to be put into. We have a standard for almost every type of pipe but we also have construction specifications and in these construction specifications we will spell out what type of soils the contractor will encounter.

QUESTION (Dr. Millette): What about the type of water that he would encounter; is that included?

ANSWER (Mr. Warden): Yes.

QUESTION (Dr. Millette): There are some water utilities in the Northeast that require an inner coating on asbestos-cement pipe to possibly prevent corrosion problems. Have you ever specified or used coating?

ANSWER (Mr. Warden): We have never used linings in the AC pipe. We only had one case that I know of and that was in California where the water had an aggressive index of less than 10. So we actually did not put AC pipe in because we felt that the water was too aggressive for that type of pipe. We did use a double cement lined ductile iron pipe with an asphaltic seal coat but we have never used any linings and I do think that linings are something that the AC Pipe Association is going to have to address.

PANEL ON DEVELOPMENT OF SUBSTITUTES

Chairman: Richard J. Guimond
U.S. Environmental Protection Agency
Washington, D.C.

Panelists: Mr. Robert Moore
Elson T. Killam Associates
27 Bleeker Street
Milburn, N.J. 07041

Mr. John Gurtowski
Materials and Processing Division
Naval Air Systems Command
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Mr. Roy Steinfurth
Insulators Health Hazard Program
Asbestos Workers International
Asbestos Workers Union
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Mr. James F. Reis
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Knoxville, MD 21758

CHAIRMAN RICHARD J. GUIMOND

The topic for the panel is the Development of Substitutes. The purpose of the panel is to discuss the development of substitutes from a variety of perspectives. We have people from various organizations and vastiy different interests to consider the development of substitutes, the technical problems, the economics, the health risk aspects, from the concerns of their individual responsibilities.

MR. ROBERT MOORE

The American Society for Testing and Materials is a volunteer, non-profit organization devoted to the development of product standards and test methods. Standard and test methods for asbestos-cement products are under the jurisdiction of Committee C-17, one of the Society's 135 technical committees.

Committee C-17, at present, consists of 59 members. Seventeen members are classified as producers; these members have 9 votes, the rest being non-voting members. Ten members are classified as consumers or users, seventeen as general interest members, and five are affiliate members.

Membership in Committee C-17 includes representatives of producers of asbestos-cement products from firms in the United States, Mexico and Belgium. Membership also includes producers of asbestos fibers, producers of cement, representatives of U.S. government agencies, representatives of State and municipal agencies, consulting engineers, and contractors. The voting strength of the various interests is such that producers of asbestos-cement products have about one-fifth of the total votes on the Committee.

Committee C-17 was founded in 1947 when the need for standards for asbestos-cement products was perceived to be urgent. The first Chairman of the Committee was Douglas Parsons of the U.S. Bureau of Standards.

The Committee meets twice a year in January and June. Task groups studying particular problems often meet between the main Committee meetings. Although business is transacted and problems discussed at the meetings of the Committee, all questions relating to technical standards are decided by letter ballot. The ASTM develops standards by the consensus method. This means that basically all interests must agree before an action becomes final. In addition, the Committee must follow strictly the detailed regulations of the ASTM which requires that interests must be balanced among producers, users and general interests, that a satisfactory percentage of ballots must be returned, and that any ballots which contain negative notes must be discussed and appropriate action agreed-upon.

Committee C-17 includes several sub-committees:

Sub-Committee C-17.01 - Editorial and International

This sub-committee is responsible for editorial content of standards and test methods. In addition, this sub-committee has the function of acting as the U.S. TAG (Technical Advisory Group) to the Technical Committee 77 of the International Standards Organization (TC 77 covers international standards for asbestos fibers and asbestos-cement products).

Sub-Committee C-17.02 - Research

This sub-committee helps to coordinate and collect new information with regard to asbestos-cement products and their uses. The Research Committee also monitors round robin product tests.

Sub-Committee C-17.03

This sub-committee is in charge of developing standards for asbestos-cement building products, including flat and corrugated sheets, insulated sandwich panels and asbestos-cement shingles. A major current use for asbestos-cement sheets is packing for cooling towers.

Sub-Committee C-17.04

This sub-committee develops standards for asbestos-cement pipe including pipe for sewers, water mains, drainage and under drains.

Current activities in Committee C-17 include development of a recommended standard for installation of asbestos-cement sewer pipe. In addition to information with regard to proper installation of the pipe to provide satisfactory structural and hydraulic performance, the standard will include information as to proper methods for cutting and drilling operations in order to avoid eventually dangerous occupational exposure.

The Sub-Committee on Research has been receiving updated information on the Water and Power Resources Services tesing of autoclaved and normal cured asbestos-cement pipe in sulfate soils and information on a test program to develop further information on structural strength of buried piping conducted by Utah State University.

The standards developed by the Committee include a list of definitions peculiar to asbestos-cement products and a number of standardized test methods such as tests for crushing strength of pipes, in addition to product standards.

Product standards include dimensional requirements, tests of strength, and certain chemical tests. The requirements for flexural strength, crushing strength, bursting strength, and joint tightness are based upon a combination of requirements for construction use and consideration of manufacturers' standards.

Because of developing concern over the possible effects of asbestos fibers, together with the possibility that new products having properties similar to asbestos cement products may be developed, the Committee is currently considering changing its scope from "products deriving their essential properties from a mixture of asbestos and fibers and cement" to "fiber reinforced cement products."

The concensus method of developing standards provides a forum where a broad range of interests can meet and develop standards which are suitable to all segments of the population. The procedure of letter balloting means that those who are not able to attend the meetings can share equally in the work of the Committee. It furthermore means that any additional information required to come to a position on a given question can be obtained and a ballot can be voted in the absence of group pressures.

The standards are not static; they are undergoing a continuous process of change as new information becomes available or the need for new products becomes evident. One example of this is the standard for transmission pipe. This standard permits an engineered design of transmission piping using pipe particularly tailored to the hydraulic requirements rather than the used standard classes of pressure piping. In cases where pressures are accurately known or controlled, transmission pipe permits a more economical use of material.

The committee welcomes wide participation in its work by interested persons. The basic requirements for membership include membership in the ASTM and a knowledge of the field.

MR. JOHN GURTOWSKI

Pressured by reports of health problems attributed to asbestos, restrictions on the volume of asbestos-contaminated air to which personnel may be exposed, worker unrest, the high cost of making work areas safe and an executive order to find an alternate material for Chrysotile AAA fiber (available only from Rhodesia), the Naval Air Systems Command embarked upon a program directed toward identifying substitute/alternate materials and in replacing asbestos components with them as soon as their potential for each specific application can be verified.

At the present time the Naval Air Systems Command has forty (40) different types of aircraft in its inventory and the task of identifying each asbestos-containing component in each type of aircraft and in its weapons and in finding satisfactory alternate materials for all of them will be a long term costly effort.

To expedite the investigation the Naval Air Systems Command has confined its first efforts to the newest aircraft in its inventory which include the F-18, F-14, AV-8A, and CH-53E models. Here action is being taken to identify acceptable alternate materials as promptly as possible and make them available as replacements when a shortage of the asbestos components is revealed either by operating personnel or by the parts manufacturer. Admittedly, this is somewhat of a "piece-meal" approach to solving a major problem, but it will, hopefully, permit the Fleet to keep its aircraft flying while the search for alternate materials continues.

To date, we have located and identified a large number of aircraft components which contain asbestos in various amounts, none of which have been found to release fibers in any significant concentrations during flight operations. Regardless of this non-hazard situation, knowing that the components may not be available in the future, they have been listed for replacement with parts containing no asbestos.

One major concern requiring costly evaluation is the replacement of asbestos-containing brake linings in aircraft. Here we are attempting to substitute carbon linings, however, FAA regulations require a very costly, long-term qualification test prior to acceptance. Currently, neither funds nor aircraft are available to complete such a test. By using brake linings containing asbestos, we have replaced very toxic beryllium brakes; however, if we cannot find a satisfactory substitute for the asbestos fiber, we may have to go back to the more acutely toxic beryllium brakes on certain high performance aircraft.

However, the most serious related problem facing the Naval Air Systems Command involves finding alternate materials to replace the asbestos containing thermal insulating liners in missiles and rockets. Little progress in this area has been made.

Preliminary funding requirements to conduct an intensive program to find acceptable thermal insulating liner materials may exceed $1 million. At the present time, that type of funds is not available to us. In our search for alternate materials, the Naval Air Systems Command is evaluating a variety of materials for specific applications: steel wool, quartz fibers, ceramic fibers, graphite, E-glass, S-glass, Refrasil, polyamide fibers, ground cork, clay, and nylon fibers. From the results to date it is apparent that some asbestos containing components, because of their critical application in aircraft and missiles may never be replaced.

One of our major concerns to-date is the great fear of asbestos created by widespread publicity regarding its potential carcinogenic nature. Let me cite two examples:

The leading edges of helicopter blades are normally protected from sand and/or rain erosion by strips of titanium or stainless steel. The adhesive used to bond the strips to the blade contained 1 percent asbestos which, after cure, was never touched. Operators insisted on hazard pay in using this material. In a similar situation, an adhesive containing 6 percent asbestos, aluminum powder and another filler, was used to detect cracks in the spars of helicopter blades. The material was used in both manufacturing and in repairing operations. Shutdown of both operations was threatened by fear of asbestos exposure. Fortunately, we were able to find adhesives for these operations which did not contain asbestos fillers, and work was permitted to continue.

In conclusion, we, in the Naval Air Systems Command, hope that no sweeping directive will be forthcoming in the near future banning the use of asbestos or setting exposure limits at such a low level as to make compliance impossible to achieve.

Even so, the Naval Air Systems Command will continue its active program to find alternate materials as rapidly as possible and will continue to find reasonable efforts to solve at least a major portion of the asbestos problems.

In the long run, it is our objective to replace as many of the asbestos containing components in our aircraft and weapons as possible with so called "safe materials".

MR. ROY STEINFURTH

While the use of asbestos has been extremely curtailed in the insulation industry and consequently exposure by our members to asbestos has been drastically reduced, we are now, however, experiencing an increase in exposure due to renovation work, maintenance, asbestos removal and demolition.

We regretfully wish to inform you, however, that in asbestos removal and demolition we can expect a great upsurge in asbestos-related disease in workers not associated with our organization. This is due to unscrupulous companies, industries and contractors using non-skilled, low-paid employees for asbestos removal, and also using unregulated dumping sites. Also many removal and demolition sites are in crowded urban areas compounding the risk of contamination to innocent people.

Substitute Materials

Statistics show that between 2/3 and 3/4 of asbestos products manufactured in this country are being used in construction. However in most of these products, the asbestos is locked or sealed in, and safe work practices can practically eliminate most dangerous fiber exposures.

In other types of non-asbestos materials being used, we are starting to experience a great deal of concern and some health problems.

1) Asbestos free calcium silicate -- some brands show a rather large amount of free silica. Silicosis could result.

2) Man-made fibrous insulation materials such as rock wool, mineral wool, slag wool, fibrous glass, Kaowool, and others -- we are constantly receiving letters and phone calls from our local union officers and our members complaining about severe dermatitis, eye and ear infections and, of course, many upper respiratory tract infections.

3) Extruded foam rubber products -- exposure to toxic fumes from adhesives and also solvents and chemicals used for cleaning hands, tools and equipment.

4) Various insulation cements used for insulating pipe fittings, equipment, pumps, etc. -- contain mineral wool. Portland cement and other materials cause severe skin and hand irritation problems -- very dusty when mixing - protective equipment must be used.

5) Styrofoam, urethane -- require respiratory protection in all applications, mixing, spraying and foaming (.02 P.P.M. to M.D.I. (methylene diisocyanate) and T.D.I.'s (toluene diisocyanate) independent fresh air supplied respirator) -- emphysema from dust, cutting.

6) We have in the past and will continue in the future to be exposed to hot and cold tar pitches which we use to secure many various types of insulation materials to equipment, pipes, tanks, etc. We are also using many new types of adhesives, fasteners, electric welding devices and other methods. Many of these insulation products are being installed in plants, coke ovens, refineries, chemical plants and other factories where a combination of toxic or carcinogenic materials may be present.

We strongly believe intensive impartial independent research should be conducted on any new insulation product before it is released for manufacturing and application. We in no way desire to be exposed to materials or methods such as used in the asbestos fiasco.

As a member of the OSHA Construction Safety and Health Advisory Committee I was appointed to serve on a special 5-man sub-group to review the current statistics and regulations and to draft new language that would allow the existing statistics to be applied to construction. This deliberation took approximately a year and the finished report is now in the process of being approved, rejected or modified by the Assistant Secretary of Labor, Eulah Bingham. This report will also apply to any future health statistics. Perhaps between this report and the new OSHA Construction Department led by Mr. Stephen Cooper and the Toxic Substances Control Act, any new materials in our industry will be fully analyzed and proper precautions can be taken preventing any new rash of occupational disease.

More legislation can and should be enacted and enforced to protect the working people from the unscrupulous manufacturer or employer who puts profits ahead of human lives.

MR. JAMES F. REIS

As was evident from the product sessions and round table discussions earlier today, one of the major points that industry has tried to convey to EPA and CPSC in relation to their rulemaking on asbestos and their efforts to develop information on substitutes is a basic precept of the free enterprise system: that is,

> "If substitutes for asbestos and asbestos products were technologically and economically feasible, the market would have readily adopted them."

Incorporated into this statement are many pressures that industries using asbestos have faced over the past ten years. Among them are:

1. the increasing price of asbestos

2. the cost of asbestos products vs. substitute products

3. the availability of asbestos vs. substitute materials

4. the cost of meeting existing regulations

5. the concerns of industry due to the uncertainty created by regulatory agency action and/or lack of action

6. the concern of industry for the health of its workers

7. the concern of increased potential liability for users of asbestos

8. the increased cost of insurance

9. the increased adverse publicity some of which we feel has been unfairly generated by the regulatory agencies

With all of the above factors serving as incentives for industry to remove asbestos from its products or to find replacement products, why in 1980 does much of U.S. industry and in fact world industry continue to use asbestos and asbestos products.

The answer is three-fold. First, to date, many substitutes have not proven to be economically and/or technologically feasible.

Second, there is a significant body of medical evidence that demonstrate that asbestos when used properly need not present an occupational hazard in the workplace nor a hazard to the general public.

And the third explanation which will be addressed tomorrow and Wednesday at this workshop is that of all the environmental agents used in industry today, probably more is known about the health effects of asbestos than any other product. Industry, as well as EPA and CPSC, has no desire to manufacture products that in many cases are more expensive and may exhibit poorer performance, just to find out that these products may present a long term adverse effect on the health of workers or the general public.

A case in point is the introduction by DuPont in the early 1970's of a product called "Fybex", a potassium titanate fiber promoted as a replacement for asbestos in plastics and friction materials. I have never seen an estimate of the cost of the research work done by industry in evaluating this material as an asbestos substitute, but it would probably be conservative, based on the numbers shown by Mr. Brunhofer this morning, to talk in millions of dollars. In 1974, DuPont withdrew this material from the market because initial testing indicated it could present a health hazard to humans. A laudable move on the part of DuPont; but a real life example of the problems that must be anticipated in the search for substitutes for asbestos.

The asbestos industry has made a conscientious effort to categorize asbestos products in order to identify those products which can be used safely and those products which present the greatest potential for uncontrolled release of respirable asbestos. The product categories the industry adopted are:

> Encapsulated - Those products which during any reasonable foreseeable use do not release fibers in concentrations in excess of the mandated OSHA limits. In many cases fiber release from these products is below detectable limits - that is, below 0.1 f/cc.
>
> "Locked-in" - Those products which do not release fibers in concentrations in excess of the mandated OSHA limits when fabricated and installed using proper work practices and/or tools.

Friable - Those products which can release fibers in excess of the mandated OSHA limits during routine handling and use.

It is in the friable category of products where Johns-Manville has expended its efforts to develop substitutes and where we feel the substitute approach is the best solution to eliminating potential hazardous exposures.

Today, all calcium silicate block and pipe insulation produced by Johns-Manville does not contain asbestos. Nor do any of our insulating cements. As a supplier of asbestos, we discontinued the sale of asbestos to the joint cement industry in 1976 and in some cases worked with the manufacturers to assist them in finding substitutes.

It is rewarding to see that EPA and CPSC have chosen to devote half of this workshop to the health aspects of substitutes. The asbestos cement pipe industry, in particular, has been extremely concerned with EPA's hesitancy toward taking a balanced approach to studying the health risks associated with all types of piping materials used for potable water supplies. Despite a significant body of evidence indicating that there is no danger to health from drinking water transported through asbestos cement pipe, EPA continues to caution states and municipalities about using this product. It would seem reasonable that similar precautions should be issued for galvanized iron, PVC, and asphalt and coal-tar lined iron and steel pipe, all of which can contribute minor amounts of known carcinogenic agents to water supplies.

All carcinogenic agents conform to certain accepted biological principles. There is nothing unique about asbestos, except that it is ubiquitous in the environment and much is known about it. There is no valid reason, scientific or otherwise, to treat asbestos differently from any other carcinogen.

If EPA plans to eventually ban the use of asbestos and encourage or mandate the use of substitutes for asbestos, then it is logical to assume that the agency intends to apply this policy to all carcinogenic agents regulated under the Toxic Substance Control Act. Any valid economic evaluation of the impact of this regulatory policy must be extended to include all carcinogenic agents and not just asbestos. Any narrower analysis would be discriminatory.

It is Johns-Manville's position that products which contain asbestos in an encapsulated or locked-in form can serve a useful function in our modern technological society and that these products when used properly, do not present a hazard to the health and safety of workers or the general public. The many valuable products made with asbestos should not and cannot be regulated out of existence unless there is a demonstrated and overriding benefit to the public in doing so.

MR. BARRY CASTLEMAN

As you know, most of the products in the asbestos industry are quite old. The patents for asbestos insulation and roofing predate 1890. Asbestos-cement was introduced at the turn of this century.

Mr. Manville, who ran the Johns-Manville Corporation for the first quarter of this century, was particularly proud of the fact that he never spent a dime on research laboratories.

My own interest in asbestos started in 1970. I was in graduate school learning about air pollution. My background is in chemical engineering. I was just looking for something interesting to study, and I tripped over asbestos. I took a look at the way they were spraying it on the buildings for construction, all over the City of Baltimore where I was in school, and I thought, "Doesn't anybody know that stuff causes lung cancer, and mesothelioma? Doesn't anybody know that the neighbors of asbestos factories get mesothelioma and that the family members of asbestos workers get mesothelioma just from the dust that walks home on the guys' clothes? And people that live near factories -- children that have played on dumps --" this was all in the medical literature in 1965.

This medical literature was based on experiences with the asbestos products that had long been in manufacture by the companies that were in that business. Were they willing to sell less asbestos to save people's lives?

The gentleman from the Navy might have more concern if he saw the side of the use of asbestos that I have seen. I am involved very often in litigation involving people who worked in Navy yards, and have developed cancer and asbestosis as a result of -- sometimes just a few summers of work there.

While visiting NIOSH in 1974, I was told a curious story. One of the inspectors had gone to a Raybestos-Manhattan plant and seen a dry-weaving operation right in the middle of the floor, and the rest of it was wet weaving. The inspector had asked the plant manager how come they do not shut down that dry weaving operation, it was throwing dust all over the plant. He was told, "We have specifications from the Navy requiring so many threads to the inch, which, in effect, specifies dry-woven asbestos cloth."

NIOSH went to the Navy and said to me that they were just told to get lost when they told the Navy to do something about the specifications.

By this time I was working for environmental groups, so I dashed off a quick petition to the Secretary of the Navy, and just to make sure he read it, I told Jack Anderson a little bit about this story and he wrote something, too. This is one of many ways that I learned to operate in trying to deal with these hazards, as an individual.

The attitudes of the industry have fascinated me. The only voluntary removal of asbestos from a single product was children's modeling clay after Dr. Irving Selikoff found that something like 50,000 pounds of modeling clay used by the elementary schools of New York was 50 percent asbestos. They were making puppets with asbestos, and it was even in the Girl Scout Handbook how much asbestos to use to make puppets.

To this day, the only product that I know being voluntarily written off as an unacceptable use of asbestos by the asbestos industry at large was modeling clay.

Five years later, in 1976, a woman in West Chester, Pennsylvania, was making modeling clays for elementary schools, using Johns-Manville asbestos that she bought from a distributor. I spent the next several years trying to convince Johns-Manville not to sell its product through distributors because Johns-Manville can not tell the distributor whom not to sell it to. And since only 2 percent of their sales was to a distributor, I thought they could easily do without it.

Johns-Manville opposed the ban on drywall spackling, as did the Asbestos Information Association and Union Carbide, despite the fact that 10,000 tons of asbestos per year was used in spackling compounds. The lungs of drywall workers on X-ray are as damaged as those of insulation workers, according to recent medical reports.

As for substitutes, I am extremely pleased to see that there is now such an interest in developing substitutes. I mean money, research and development resources of some of the largest corporations in this country, devoted to finding substitutes for asbestos. This has led to widespread substitution of asbestos in insulation; and break-throughs are now being made in friction products, packings, textiles, plastics, and fiber-cement products, to name the more prominent cases. It is about time, and I am happy to see that.

I think the most crucial aspect of implementing substitution is the availability of substitutes. The EPA cannot write regulations unless you people come forth with viable, commercial substitutes for asbestos, with products that are quite reasonably capable of replacing asbestos, considering the public health hazards of asbestos and the hazards of the substitutes.

I have never heard of a single substitute for an asbestos product that could rival asbestos for hazard. I am sure more needs to be known about that, but we still need to decide what to do today, while we are finding out.

My personal hope is that we can prevent, world-wide many needless deaths from exposure to asbestos.

One of the people who I am involved with in compensation proceedings is a woman who worked as a secretary in a plant where asbestos-cement panels were sawed up. She worked two floors below the cutting room of where they sawed up those asbestos panels. This woman has mesothelioma today. It does not take that much exposure to kill.

Yet today I find near the affiliates in India, of the Johns-Manville Corporation and British firm Turner and Newall, conditions which you would not believe, conditions which we thought went out with Merewether's reports in 1930. I have pictures of a two-year old child sitting on an asbestos cement waste dump right in front of his house beside Johns-Manville affiliate in Ahmedabad. Houses in the neighborhood are built of asbestos cement waste, and untreated wastewater pours its opaque burden into the surface waters of the region.

After hearing what I have heard today about the availability of substitutes, I think we are headed toward a tremendous reduction in the use of asbestos worldwide. People in a lot of countries are gearing up the same as we are here. I think that the United States will probably lead the way. Hopefully, Quebec will see the mistake that it is making, getting into the asbestos business at this time.

In Ontario, Johns-Manville just shut down a plant making asbestos cement pipe when the 170 workers went out on strike. They said there is not enough market for it and that they were shutting down other plants in the United States, too. This plant in Toronto opened in 1947. Over the last 20 years, 120 claims have been allowed for asbestosis and mesothelioma and around 50 workers have died from asbestos diseases.

Meanwhile, Quebec is thinking of going into the asbestos business, nationalizing its asbestos mines and being the death merchants of the 1980's, selling the stuff all over the world.

The availability of substitutes today convinces me that the use of asbestos is really going to decline. It is not something that we have much longer to wait for; it is really here. You have done a good job, and now it's EPA's turn.

DISCUSSION ON DEVELOPMENT OF SUBSTITUTES

QUESTION (Mr. Gurtowski): From 1935 to 1943, I was a chemist in the American Manufacturing Company. We manufactured loaded insulation. We used from 50 to 70 tons of the material a month. When I checked back several months ago to see how many people had died or had cancer, I was quite surprised to find there were two or three people. Most of the people, they told me, died from over-smoking. What had happened to the other 500 people who were working in the plant with me?

ANSWER (Mr. Castleman): You are a fortunate man and you now have the opportunity to provide some protection for people who are currently in similar circumstances. Those circumstances are now well recognized to be dangerous. Statistical studies on the population establish that by working in circumstances such as you described, you are running a high risk of acquiring adverse health effects.

QUESTION (Chairman Guimond): I have a question that I would like to direct to Mr. Moore, relative to the ASTM (the American Society for Testing and Materials) developmental standards. One of the concerns that a few people have expressed to me is that in some cases Federal (and other) specifications require that varied amounts of asbestos be in a product, whether or not the product really needs it for performance purposes.

First of all, I would like your comments on these specifications, and second, to what extent do you see the performance standards, either standards by ASTM or other types of organizations, being useful in determining whether or not a substitute will perform adequately.

ANSWER (Mr. Moore): Number one, my recollection is that ASTM specifications do not specify formulation of the products. They specify performance of the product. I am also of the understanding that it is now Federal policy that such a standard be used wherever practical. The Federal government is using ASTM standards in most cases.

QUESTION (Chairman Guimond): I was asking a broader question, and not necessarily about ASTM; that is, do you know of other kinds of stipulations such as Federal specifications that might be any hindrance? Or secondly, do you think that we should broaden standards into areas where they do not currently exist, so they will help us to determine equivalence for performance?

ANSWER (Mr. Moore): I am not really aware of any such standard existing.

With regard to general performance standards, the standards that are now developed do provide for specific performance for various types of materials and are significantly different depending on the characteristics of the materials, such as plastics, in-duct wiring, reinforced concrete, and asbestos-cement.

It is very difficult to come up with an overall generic specification that will cover all circumstances. It requires experience in the field as to the performance of the parts of the various products, and the particular conditions requiring one product rather than another. It is very difficult to come up with an overall standard.

QUESTION (Mr. Gurtowski): In many areas, we are concerned about thermal insulation, should we worry about exposure to various solvents in the chemical? And how is ASTM going to handle that particular problem?

ANSWER (Mr. Moore): These standards are developed by committees of people who are familiar with the characteristics of the various products, so that information is, hopefully, put together in development.

QUESTION (Chairman Guimond): Mr. Gurtowski, you were talking about the transition to substitutes in aircraft in the Naval program. Are you doing anything from the standpoint of first establishing what performance you need and then searching for substitutes?

ANSWER (Mr. Gurtowski): Yes, we look at the environment the product is exposed to (temperatures, solvents, fluids) and then try to find a substitute that has the same physical and chemical properties. The substitute we find will have to have exactly the same physical properties of the material we intend to replace.

In particular, one formulation that contained 6 percent asbestos was looked at in the aircraft where the temperature did not exceed 200°F. The specifications were very low, so through a series of experiments, we developed a new formulation. In that particular case, it was relatively simple. But for instance, if we have to protect the pilot from a fire with temperatures that will exceed 2,000°F what substitute are we going to use? The other thing we worry about is if we use glass, it can break up, and be inhaled into the lungs and could be just as dangerous as asbestos fibers. This gives you an idea of some of the things we have to do.

I have one problem now where we have an asbestos cloth that is impregnated with neoprene rubber. In this particular case we depend on the neoprene rubber to get overheated, char, and act as a thermal insulator, in addition to giving us the protection against fire. We have hundreds of materials which protect our aircraft, such as polysulfide, polyurethane sealant, and others. Many of these contain some form of asbestos, whether in a powdered form or in various lengths. The asbestos provides needed properties; at the same time the substance gives us the water proofing we need to make sure that our aircraft flies safely with our weapons systems.

In missiles, the temperatures quite often exceed 2,000°F, even though it is just for a few seconds. What material are we going to use? Glass will melt, other organic materials I do not think will work either. We are not giving up the search for a substitute, but the understanding is that we are not going to eliminate asbestos altogether. That is something that will never happen.

QUESTION (Mr. Castleman): This question is directed to Jim Reis. I would like to get a list of inappropriate or unfit uses of asbestos from Johns-Manville, or from any other company. I was told by your world fiber sales chief three years ago that such a list was being developed, but I was never able to obtain it. I presume the sale of fibers for uses that you consider off limits as well as the use of your own fiber occurs. Does this apply world-wide or just in a particular locality?

Lastly, if you have information on the vinyl chloride that leaches from PVC pipes into drinking water, which the EPA ought to know about in evaluating its alternatives to asbestos cement, will you please submit that information. I would assume that you have done some testing and I am sure that EPA would be interested in seeing what you thought.

ANSWER (Mr. Reis): As far as appropriating uses are concerned, there have been several presentations given by Johns-Manville people that identified a number of appropriate uses. We looked at each of the categories and made a conscientious effort to try to eliminate sales to those categories which we identify as inappropriate.

QUESTION (Mr. Castleman): What are the categories that were inappropriate? There could not be too many of them; can you remember?

ANSWER (Mr. Reis): I have listed several of them here and I could probably go on. I do not have any desire to list them right now.

QUESTION (Mr. Castleman): Well, what are they: insulation, spackling compound, children's clay, hair dryers? What else is an inappropriate use of asbestos?

QUESTION (Chairman Guimond): Mr. Reis has indicated they are developing substitutes in the areas where they feel asbestos was inappropriate. Is it implied that you are or are not developing substitutes or considering substitutes in the areas where you have locked-in fibers or the encapsulated fibers?

ANSWER (Mr. Reis): That is a particular point I did not mention, but I think it is common business sense. I do not think there is anyone in this room who uses asbestos today who is not looking at potential substitutes. A hundred years ago, asbestos was not a particularly common product in industrial use. It evolved over that period of time; it has become very popular, and like many other products in industry, we did not foresee the possibility that its use would become a lot less than it is today. So we continue to look at substitutes. Obviously, Johns-Manville, as any other company here that uses asbestos, is aware of the government regulatory actions, and we will look at substitutes and evaluate them from our viewpoint.

QUESTION (Mr. McCarthy): I am with Minerals Week. I would like to address this question to the representative from the asbestos workers.

What are your feelings about being somewhat of a guinea pig for potential health effects from replacements for asbestos. Are you actively involved in ensuring that the laboratory tests meet specifications before you start using those kinds of materials?

ANSWER (Mr. Steinfurth): We do have many materials analyzed by a well known firm. If I mentioned the name, you would agree that they have a good reputation, both in industry and government. I happen to have two sons who are asbestos workers. They have been working with a particular fibrous product in a nuclear energy plant. They have been working seven days a week in a so-called spread room, cable room and so forth. They came to my house yesterday and I could not recognize them because their eyes were almost closed and their faces looked like they had the measles. I guess you know now that they were working with Kayo wool. They were laying it very gently in the cable area.

Of course the temperature in this spread room runs about 105 to 110°F. They did not have the proper safety equipment, respiratory equipment and so forth.

We have also found that some protective clothing, which many people call "paper coveralls," should not be worn in heated areas because they induce heat stress and eventually heat prostration, or heat stroke.

I am sorry, I missed parts of your question, please state it again.

QUESTION (Mr. McCarthy): Basically, I am looking for what the asbestos workers might have available to them, to ensure that that kind of result does not occur to workers in general. Is there a lobbying effort on your part? Is the government actively soliciting some prerequisite regulations on your behalf before it goes into general use? Is there any intercommunication between you and specific corporations that are looking at asbestos and categories they have considered inappropriate uses?

ANSWER (Mr. Steinfurth): We do not have that much involvement with some of the current products. In fact, this is supposed to be covered under the Toxic Substance Law--let us leave it that way. Up to date, you know as well as I do, the law has not worked the way it should have worked. We have to depend on ourselves and independent scientists. We, in our organization, feel we can no longer take the word of any industry-oriented scientist, after the problems we have encountered with asbestos. We do analyze products, see what they are made of, get the opinion from not only the person who analyzes the products, but also from different authorities, such as Dr. Selikoff and Dr. Cooper, who both do work for us and are able to help us immensely.

QUESTION (Mr. McCarthy): If the workers find themselves in these kinds of predicaments and if they really can not judge the effect of the substitute without, perhaps, lengthy exposure experiments, what state does the consumer find himself as far as exposing himself to asbestos and to what extent can he approach the government or industry, or, perhaps, an organized labor union to ensure his own safety?

I mean, asbestos receives enough publicity that people are coming to grips with it; consumers are looking for labels in areas before they replace asbestos tiles, tools, etc. What about replacement parts? Are consumers being led to believe that they are safe when actually we have no evidence to the fact?

ANSWER (Mr. Steinfurth): What you say is true. Some consumers are led to believe that some products are dangerous. We have had problems with some products. I have to put it very gently and say that if we do have a problem and the contractor or owner does not wish to cooperate, we have methods to make them cooperate.

REMARK (Mr. Gurtowski): We have activities that we do at the Navy Environmental Health Center related to all of these organic materials to ensure that the workers are protected.

One of the things we find to be the worst culprit, as far as toxicity is concerned, is that a man becomes so familiar with a product that he gets careless. We have had several Ph.D.'s who had to retire because of exposure. One man should have known better, but he had worked with the material for so long that he got a little careless and he paid for it.

ROUNDTABLE DISCUSSION SESSIONS

The roundtable discussions were provided to give all participants a chance to supply information on technical and economic substitutes for asbestos to EPA. The roundtables discussed asbestos substitutes for eight categories: friction materials, gaskets and packings, reinforced plastics, flooring, paper and roofing products, textiles, asbestos-cement sheet, and asbestos-cement pipe. These roundtable discussions were held concurrently from 3:30 - 5:30 p.m., the first day of the workshop.

A list of general questions about asbestos substitutes for asbestos was distributed to all participants to help guide the discussions, followed by a similar but more detailed list for each product category. These questions and the summaries of the roundtable discussions follow on the succeeding pages.

1. What are all of the uses and applications in this product category?
2. What fibrous or product substitutes exist for these applications, products, and uses?
3. What are the technical performance characteristics of the substitutes in this category?
4. What are the lifecycle costs of the substitutes in this category?
5. To what extent can existing capital equipment be used to produce substitute materials or products?
6. Would energy requirements be changed substantially by switching to production or use of the non-asbestos material?
7. What are the performance standards or product specifications required of a substitute? Would any of these standards be unnecessary if substitute materials were used?
8. What research and development is underway in this product category?
9. Identify any health and environmental effects of the materials used to substitute for asbestos in this product category.

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SUBSTITUTES FOR ASBESTOS FRICTION MATERIALS

1. What are the basic ingredients used in nonasbestos disc brake and drum brake lining formulations? Of particular interest are the materials used to substitute for asbestos. What are the physical characteristics and size distribution of fibers used to substitute for asbestos?

2. What are the performance characteristics and the problems associated with the use of substitute products for drum brake linings containing asbestos? Do the non-asbestos pads provide adequate performance in the categories of lining wear, noise, wet recovery, etc?

3. What non-asbestos friction materials are available for applications other than in automobiles and light trucks (aircraft, heavy duty vehicles, etc.)?

4. What problems hinder the commercial utilization of non-asbestos drum brakes? Estimate research and development costs and time for development of commercial non-asbestos drum brake linings. How long did it take to develop non-asbestos disc brake pads?

5. If a new car is designed to use non-asbestos disc brakes are replacement linings for that vehicle also non-asbestos? What are the problems associated with providing a replacement lining for a car which has been designed to use non-asbestos brakes?

6. What mechanisms are there for the transfer of technology to other companies who manufacture brake linings? If the use of asbestos in friction materials such as brake linings and clutch facings were prohibited how would your company acquire the technology to manufacture non-asbestos friction materials?

7. Identify any health and environmental effects of the materials used to substitute for asbestos in friction materials.

SUBSTITUTES FOR ASBESTOS GASKETS AND PACKINGS

1. The background information report identifies two main types of asbestos gaskets: compressed sheets and beater-add sheets. It also states that asbestos packings are generally made from yarns impregnated with a lubricant, and that packings may either be leak proof (for valves) or permit leaking (for pumps). What other types of gasketing and packing materials containing asbestos exist?

2. Fiber substitutes for asbestos in gaskets and packings include silica, graphite, and ceramic fibers, as well as some synthetic fibers: aramids, Kevlar©, Teflon®, Gylon®, and Nu-Board. What other fibrous substitutes are available? What non-fibrous substitutes are available?

3. How do available substitutes perform with respect to 1) resistance to heat, 2) resistance to pressure and friction (in the case of packings), and 3) resistance to chemical attack? Do synthetic fibers perform better than the natural (silica or graphite) fibers? How do non-fibrous substitutes perform?

4. The cost of substitute fibers ranges from .75 to 32 times the cost of asbestos fibers. However, these are not lifecycle costs. How do the cost of installation and maintenance frequency influence the lifecycle cost of a substitute gasket or packing?

5. In the case of substitution of other fibers for asbestos in gaskets and packings, can original equipment still be used in production of the nonasbestos product? What are the projected costs of any equipment modifications that must be made?

6. Would energy requirements be changed substantially by switching to production or use of the nonasbestos material?

7. What performance standards or specifications are required of gasketing and packing materials? Do substitute materials meet these standards and specifications? Would any of these standards be unnecessary if substitutes were used?

8. The background information document lists a large number of non-asbestos raw materials from which gaskets and packings may be fabricated. What research is planned or underway to develop additional new materials?

9. Identify any health and environmental effects of the materials used to substitute for asbestos in this product category.

SUBSTITUTES FOR ASBESTOS IN REINFORCED PLASTICS

1. What are all of the major uses and applications in this product category?

2. What fibrous or product substitutes exist for these applications, products, and uses?

   We know that glass fibers, carbon fibers, aramid fibers, clay, mica, wollastonite, calcium sulfate and talc can be used to replace asbestos fiber in phenolic molding compounds and other plastics. What other materials can be used to replace asbestos in these plastics? We know that the types of plastics that are used include phenolics, urea, melamine, unsaturated polyesters, diallyl phthalate prepolymers, epoxies, silicones, polypropylene, and nylon. What other plastics are used to make reinforced plastics?

3. What are the technical performance characteristics of the substitutes in this product category? Are there any applications for which no substitutes have been found? Have substitutes been found for phenolic molding compounds in commutators and rotors for electrical and automotive appliances? Is there data on the long term performance, particularly durability, of these and other substitutes?

4. What are the life cycle costs of the substitutes? We would like information on costs of production, maintenance, and replacement (i.e. product lifetime). There can be a rather large variation in cost of filler material for plastics. Does this cause any large variations in final product cost? If so, what are they?

5. To what extent can existing equipment or processes be used to produce substitute materials or products? If existing equipment or processes must be modified to accommodate substitute production, what changes must be made and what are the costs of those changes?

6. Would energy requirements be changed substantially by switching to production or use of the nonasbestos material?

7. What are the performance standards of product specifications required of a substitute? Would any of these standards be unnecessary if substitute materials were used?

8. What research and development is underway or planned in this product category?

9. Identify any health and environmental effects of the materials used to substitute for asbestos in this product category.

SUBSTITUTES FOR ASBESTOS IN FLOORING

1. What are all of the applications and uses of asbestos in this product category: Are there any other types of asbestos containing flooring other than floor tile and sheet flooring?

2. What fibrous or product substitutes exist for these applications, products, and uses?

3. What are the technical performance characteristics of substitutes in this product category? Are there any applications for which no substitutes have been found?

4. What are the lifecycle costs of substitutes? We would like information on costs of production, maintenance, and replacement (i.e., product lifetime).

5. To what extent can existing equipment or processes be used to produce substitute materials or products? Would new equipment or processes be required to produce or use nonasbestos vinyl flooring? If so, what would be the costs of developing the new equipment or processes?

6. Would energy requirements be changed substantially by switching to production or use of the nonasbestos material?

7. What are the performance standards or product specifications required of a substitute? Would any of these standards be unnecessary if substitute materials were used?

8. What research and development is underway or planned in this product category? When do various companies project that they can develop prototype substitute materials? When do they expect nonasbestos vinyl products to be commercially available?

9. Identify any health and environmental effects of the materials used to substitute for asbestos in this product category.

SUBSTITUTES FOR ASBESTOS PAPER AND ROOFING PRODUCTS

1. The paper products that are listed below contain asbestos and have multiple uses:

   a. Flooring felt

   b. Roofing felt

   c. Beater-add gaskets

   d. Pipeline wrap

   e. Millboard

   f. Electrical insulation

   g. Commercial paper

      - General purpose thermal insulation
      - Muffler paper
      - Corrugated paper

   h. Speciality papers

      - Cooling tower fill
      - Transmission paper
      - Electrolytic diaphragms
      - Decorative laminates

   i. Beverage and pharmaceutical filters

   Are you aware of any other asbestos-containing paper products? What are they and what are their uses?

2. The following substitutes exist for the paper products that are listed above:

   a. Flooring felt - potential substitutes that have been studied include fiberglass, cellulose, Nomex®, other polymeric fibers.

   b. Roofing felt - organic felt, fiberglass felt, single-ply membrane felt.

   c. Beater-add gaskets - ceramic, Teflon®, metals.

   d. Pipeline wrap - saturated fiberglass, plastic tapes, extruded epoxys, and resins.

   e. Millboard - aluminasilicate ceramic fibers and inorganic or organic binders, ceramic fiberboards.

   f. Electrical insulation - aramid paper, ceramic paper.

   g. Commercial paper - ceramics, cellulose, fiberglass.

h. Specialty papers

- Cooling tower fillers - polyvinyl and polypropylene plastics, cellulose, aluminum, steel.
- Electrolytic diaphragms - Nafion® membrane cell.
- Decorative laminates - glass, ceramic papers.

i. Beverage and pharmaceutical filters - cellulose, fibers, diatomaceous earth, mixed wood pulp and paper.

What other fibrous or non-fibrous substitutes exist for these paper products?

3. Any number of the following factors may be considered in evaluating the technical performance of these materials:

   - strength
   - decay resistance
   - thermal resistance
   - sound deadening
   - water proofing
   - durability
   - economy

   How do substitutes for the nine types of asbestos paper products mentioned in question #1 perform relative to the factors listed above? Are there any applications for which no substitutes exist?

4. Based on the background information report, the cost of substitutes seems to be greater (up to 10 times) than the cost for asbestos products (except for organic felt used in place of asbestos roofing felt). These costs, however, are not lifecycle costs. What are the costs of substitutes, including transportation, installation, maintenance and replacement (i.e., product lifetime) costs?

5. Several asbestos paper products are manufactured using conventional paper machinery. For example, commercial papers, roofing felt, and electrical insulation are produced in this manner. Can substitute papers be manufactured using the existing equipment? Do you foresee any additional equipment costs in switching to non-asbestos substitutes?

6. What additional energy requirements do you anticipate for the production of substitute products?

7. One product specification that is consistently mentioned in the summary report is "durability." What is your definition of a "durable" substitute? What other performance standards do you consider to be essential? Are there performance standards for the production of non-asbestos paper products?

8. The summary report indicates that substitutes for the nine groups of asbestos paper products either have been or are currently being developed. What research and development is planned or underway that may effect substitutions for asbestos paper products?

9. Identify any health and environmental effects of the materials used to substitute for asbestos in this product category.

SUBSTITUTES FOR ASBESTOS TEXTILES

1. The three major uses for asbestos textiles are:
    a. Fire resistant application in
        (1) welding curtains
        (2) draperies
        (3) blankets
        (4) protective clothing
        (5) hot conveyor belts
        (6) furnace shields
        (7) molten metal splash protection aprons
        (8) rocket and missile parts
        (9) ironing board covers
        (10) theater curtains

    b. Thermal insulation in
        (1) pipe wraps for safety protection
        (2) stress relieving pads in welding operations
        (3) protective covering for hot glassware utensils
        (4) coverings for diesel engine exhaust lines
        (5) flue sleeves
        (6) braided walls in the construction of steam hoses

    c. Electrical insulation in
        (1) wires and cables
        (2) arcing barriers in switches
        (3) circuit breakers
        (4) heater cords
        (5) motor windings

    Do you have any additional major uses to add to this list?

2. The major types of substitutes for asbestos textiles are fiberglass, ceramics, organics, graphite, carbon, quartz, cotton, and special wool blends. Can you add other substitutes to this list?

3. How do substitutes compare to the asbestos use or products in technical performance?

    Fire resistant materials: Which substitutes are effective at temperatures higher than 1000°F (540°C)? Which substitutes are effective at lower temperatures?

Thermal insulation: Fiberglass is effective at temperatures below 1000°F (540°C) and ceramics at higher temperatures; however, these materials may lack strength. How important is this quality for thermal insulation applications?

Electrical insulation: Glass and organic materials can be used at lower temperatures and ceramic materials and quartz are more effective at higher temperatures. Glass is not suitable in applications where severe flexing is involved. These materials tend to have low conductivity and low density. Please comment.

4. What are the lifecycle costs of substitutes? Consider costs of production, maintenance, and replacement (i.e. product lifetime). Are there any substitutes which are available but are not yet marketable because of cost? Would economies of scale reduce costs enough to make them cost competitive? If so, which ones would become cost competitive?

5. Can substitutes for asbestos textiles be made or used with existing equipment and processes? If changes are required what are the costs of these changes?

6. Would energy requirements be changed substantially by switching to production or use of nonasbestos materials?

7. What are the existing performance standards or product specifications for textile applications? For example, asbestos fire insulation has a UL fire rating. Can substitutes meet the same standards? Would any of these standards be unnecessary if substitute materials were used?

8. What research and development is underway or planned to effect substitution of other materials for asbestos? To what extent are recently-developed or introduced substitutes such as Refrasil®, Thermo-Sil™, Zetex™, Nextel® 312, Nomex®, Teflon®, Kynol™, Durette®, P.B.I.™, Thermo-Ceram™, Fiberfrax®, Celion®, Celiox™, Alphaquartz, and Norfab® being produced and sold in the United States? How long did it take to develop these materials and what were the development costs?

9. Identify any health and environmental effects of the materials used to substitute for asbestos in this product category.

SUBSTITUTES FOR ASBESTOS-CEMENT SHEET

1. The four major types of asbestos-cement sheet (a/c sheet) are

   a. Flat sheet, used in

      (1) industrial, commercial, and residential buildings
      (2) decorative paneling
      (3) cooling towers
      (4) laboratory table tops
      (5) ovens, safes, heaters, etc.

   b. Corrugated sheet, used in

      (1) electrical equipment as an insulator

   c. Siding shingles

      (1) industrial and agricultural buildings
      (2) lining for waterways and canal bulkheads
      (3) cooling towers

   d. Roofing shingles

   Do you have any additional major applications or uses to add to this list?

2. The major types of substitutes for a/c sheet are glass-reinforced concrete, cement-wood board, other types of fiber-reinforced concrete, and wood products such as hardboard. Can you add any additional types of substitutes for a/c sheet to this list?

3. What are the technical performance characteristics of the substitutes in this product category?

   Glass-reinforced concrete, although its overall strength is high, may be weak at high temperatures. It may also be difficult to machine well. Please comment on any other limitations on the performance of glass-reinforced concrete sheet.

   What are the performance characteristics of other substitutes for a/c sheet, including cement-wood board, wood products, alumina-silica products, and fiber-reinforced concrete?

   For what a/c sheet applications are there currently no available substitutes? Lab tables and some electrical applications (which?) may be examples of applications for which there are currently no available substitutes.

4. What are the lifecycle costs of various substitutes for a/c sheet? Are

there any substitutes which are available but are not yet marketable because of cost? Would economies of scale from increased production of the substitutes mitigate this problem?

5. To what extent can capital equipment currently used for a/c sheet production be used to produce fiber-reinforced concrete or other substitutes for a/c sheet?

6. Would energy requirements be changed substantially by switching to production or use of the nonasbestos material?

7. What are the performance standards or product specifications required of a substitute? Would any of these standards be unnecessary if substitute materials were used? For example, a/c shingles have a U.L. Class A fire rating. Can substitutes match this? Is this fire rating necessary?

8. What research and development is underway or planned in this product category? To what extent are recently developed or introduced substitutes such as fiber-reinforced cement sheet and wood products being produced and sold in the United States?

9. Identify any health and environmental effects of the materials used to substitute for asbestos in this product category.

SUBSTITUTES FOR ASBESTOS-CEMENT PIPE .

1. Identified uses of asbestos-cement pipe are pressure pipe (water mains, laterals) and non-pressure pipe (sewer mains,drainage and irrigation pipe, and electric and telephone conduit). What other uses of asbestos-cement pipe exist?

2. Only glass fiber is currently employed as a reinforcing fiber in a commercial asbestos-cement pipe product. Have any other fiber replacements for asbestos in asbestos-cement pipe been identified? Other than ductile iron pipe, concrete pipe, plastic pipe, and vitrified clay pipe, are there any products that may be used to substitute for asbestos-cement pipe?

3. What are the technical performance characteristics of the substitutes in this category? What implications do characteristics like pipe flexibility and burst strength have for the use of substitutes?

4. What are the lifecycle costs of the substitutes? We would like information on costs of production, transportation, installation, maintenance, and replacement (i.e., product lifetime).

5. Could existing equipment or processes be used to produce glass reinforced cement pipe? If changes in equipment or processes are necessary, what would be the costs of those changes?

6 Would energy requirements be changed substantially by switching to production or use of the nonasbestos material?

7. What are the existing performance standards or product specifications required of asbestos-cement pipe? Do substitutes meet these standards? Would any of these standards be unnecessary if substitute materials were used?

8. What research and development is underway or planned in this product category?

9. Identify any health and environmental effects of the materials used to substitute for asbestos in this product category.

SUMMARY OF THE ROUNDTABLE DISCUSSION ON FRICTION PRODUCTS

PANEL MEMBERS

Jeannette Wiltse -- (Moderator) EPA, Office of Pesticides and Toxic Substances

Al Colli -- EPA, Office of Pesticides and Toxic Substances

Jim Hughes -- EPA, Office of Pesticides and Toxic Substances

Jeannette Wiltse of the Environmental Protection Agency (EPA) described the EPA's interest in comments on the issues listed in the handout or any other information the participants in the discussion might want to convey. She asked about the role of substitutes in the aftermarket when, for instance, a friction material has an asbestos substitute. Mr. Drislane of the Friction Materials Standards Institute (FMSI) replied that some replacement brakes for semi-metallic original equipment brakes are nonasbestos and others contain asbestos. He suggested that perhaps after several years, like will be replaced with like.

Jeannette Wiltse of EPA asked how brake repair people know what to use as replacement parts? Mr. Drislane replied that the field has this information but the concern of the brake repair shop people is about product liability.

Jim Hughes of EPA asked if small brake manufacturers could have capital equipment and financing problems in converting to nonasbestos friction products. Mr. Drislane of FMSI replied that this will be a real problem for some of the smaller manufacturers. Jim Hughes asked if plant closures would result. Mr. Drislane replied that he could not predict that, but suggested that in 5 years most people will be using the same type of material.

Mr. Ward of General Motors (GM) said the entire brake system is designed as a unit. The engineers who make substitutes indicate that problems could result if replacements are not made of materials similar to those of the original equipment.

Mr. Brunhofer of Bendix said that the friction material is part of an overall system. Substitution should be studied carefully or else problems in safety or wear may develop. The aftermarket materials have been developed over a long period of time. He said that as you phase into a revolutionary period problems may develop, but that time is a big healer.

Al Colli of EPA said that some firms apparently do not have the technology to manufacture nonasbestos brakes. Do major manufacturers of nonasbestos brakes have provisions for licensing or do they hold the technology as proprietary?

Mr. Brunhofer of Bendix replied that his company has many license agreements today, but they are for the international market and they usually include territorial exclusions. Bendix is not aggressively pursuing licensing but has not excluded the possibility. Significant amounts of company funds have been expanded to develop new technology.

Jim Hughes of EPA said that EPA is concerned about the effects of possible regulation of asbestos on small business.

Mr. Drislane of FMSI commented that semi-metallic brake development began in 1962 before asbestos was an issue. It is utilized because it meets marketplace needs. Mr. Rosenberg of Borg Warner said that they manufacture manual clutches which use friction materials containing 50 percent asbestos. Several years ago they made a corporate decision that they should develop asbestos free friction materials. He said that they did not do this because of environmental concern from asbestos, but because they wanted to protect our employees from occupational exposure. He said that several million dollars have been expanded and they are close to their goal. They may enter license agreements or manufacture in Brazil.

Al Colli of EPA asked what tests or design consideration go into brakes manufactured for the marketplace. Mr. Ward of GM replied that if you used an asbestos lining instead of the currently-used linings, the car would still stop safely. However, the life expectancy of the braking system would be poor.

Al Colli of EPA asked if more stringent government requirements on original equipment brakes as opposed to brakes for the aftermarket would result in the manufacture of asbestos replacement for semi-metallics. Mr. Ward of GM replied that when dealing with smaller cars, the size of the braking system may be a consideration. Mr. Brunhofer of Bendix commented that semi-metallics have been designed into the system because of their high temperature properties. Organic materials (such as asbestos) have high wear rates above 350°. Semi-metallics can withstand temperatures of 650° to 700°. Most vehicles in the past operated in the 250° to 400° range. Temperatures of the new front brakes on small vehicles may exceed 400°. Wear is greater if you substitute an organic for a semi-metallic material. The difference is greatest with a small compact car with a solid rotor. Also, you will not pass SAE (Society of Automotive Engineers) or federal fade requirements on many small vehicles with a solid rotor. If you substitute an organic material for a semi-metallic, you can also develop brake lock on slippery surfaces. Mr. Chastine of Abex supported what Mr. Brunhofer of Bendix stated by saying that Abex does not compromise quality in the aftermarket.

Mr. Burgess of the Wheeling Brakelock Manufacturing Company said that they do not have the capacity or know-how of GM or Abex, but that they start where those companies leave off. Wheeling Brakelock makes very large brakes for industrial equipment. They make brakes that weigh up to 75 pounds, are 5 inches thick and 120 inches in diameter. Mr. Burgess said that the asbestos they're using is 40 cents per pound, but the stuff they have to replace it with is $8.00 per pound. Also there are problems with molding.

Jeannette Wiltse asked how big this market was, and asked if substitute materials had penetrated the market. Mr. Burgess of the Wheeling Brakelock Manufacturing Company replied that there had been no market penetration by manufacturers of substitutes. He said this is a highly specialized business with only 5 companies left out of 20 several years ago.

Jeannette Wiltse asked if substitutes had ever been tried in these applications. Mr. Burgess of Wheeling Brakelock Manufacturing Company replied that his company gives all its money to EPA and OSHA (Occupational Safety and Health Association) so they have nothing left. The size of the market is small compared to the auto market.

Jim Hughes of EPA asked approximately how much asbestos does your company use? Mr. Burgess replied that he did not want to say, but that EPA could find out from Canadian records.

Mr. Ward of GM said that many industrial machines have asbestos brakes that are essential to industry.

Jeannette Wiltse of EPA asked what are the performance characteristics of nonasbestos drum brake linings--noise, wet recovery?

Mr. Brunhofer of Bendix replied that there are four main categories for design considerations--friction stability, wear, effect on opposing surface and noise. There is information in the literature on the materials that can be used. Nonasbestos drum brakes have slightly higher friction but approximately equal wear if engineered properly. They have acceptable mating surface wear, but noise is a problem.

Someone asked why American manufacturers do not make cars with four wheel disc brakes like foreign car manufacturers. Mr. Brunhofer replied that the answer was cost. Rear brakes have become parking brakes in many applications.

Mr. Burgess said that every brake they manufacture has greatly different design requirements.

Al Colli of EPA asked how the design criteria for all these applications is determined. Is it an art or is there a scientific basis?

Mr. Burgess of the Wheeling Brakelock Manufacturing Company said the manufacturer has a starting range for coefficient of friction and it is trial and error after that. You have to have the right brake block for the job.

Mr. Moulton of DuPont said that he would like to make a comment on Kevlar® aramid fibers manufactured by DuPont. He said that Kevlar® has high tensile strength, frictional stability, and excellent durability. It is used in disc brake pads with wear levels between that of asbestos and semi-metallic materials. Kevlar® is being used in experimental drum brake linings and wet friction papers. Kevlar® does not score mating surfaces. It is used in manual transmission for the Mercedes, Audi, and Porsche. The fiber is available in a short pulp form at $3.75/lb. Only small amounts are required with deep filler materials so that the cost is between 20 percent and 40 percent greater than for asbestos with the lifetime cost approaching that of asbestos.

Mr. Brunhofer of Bendix said that their company went ahead on a crash basis because of pending OSHA (Occupational Safety and Health Association) regulations during the last 3 years. If the development had been over a longer period of time they might have investigated other materials.

Jeannette Wiltse of EPA asked if new tooling and equipment is required for nonasbestos brakes.

Mr. Brunhofer of Bendix replied that some new equipment is required for manufacturing disc brakes. Different materials require different equipment. For nonasbestos drum brakes, radical changes in processing may be required.

Jim Hughes of EPA asked how the life cycle costs of nonasbestos brakes compare with asbestos.

Mr. Brunhofer of Bendix replied that life cycle costs have not been taken into account. He said that semi-metallics have higher life cycle costs than organics; but the former brakes are smaller and lighter, therefore result in higher fuel economy.

Al Colli of EPA said that in 1985 all disc brakes on new cars will be nonasbestos. We know that Bendix, Delco, and Abex have the technology. What plans to the other companies have to obtain the technology?

Mr. Morris of Alfred University said that more basic research should be done on substitute fillers to tailor characteristics to meet asbestos applications.

Jeannette Wiltse of EPA asked how extensive is the basic research on substitute materials.

Mr. Morris of Alfred University said that in the past several years they have had three contracts in the friction area. More work should be done.

Mr. Melner of Jim Walter Research said that he represents a company that manufactures asbestos replacement material. They contracted to manufacture about 16 million pounds of the material because of rumor or fact on regulations pending on asbestos. If their substitute material works, they are concerned about possible effects from it. He said that they have not received any guidance from government regulatory agencies. As a supplier they are about to commit a quarter of a million dollars for testing.

SUMMARY OF THE ROUNDTABLE DISCUSSION ON SUBSTITUTES FOR ASBESTOS GASKETS AND PACKINGS

PANEL MEMBERS

Hugh Spitzer -- (Moderator), CPSC

Pat Harrigan -- EPA, Office of Pesticides and Toxic Substances

Kirk Johnson -- EPA, Office of Pesticides and Toxic Substances

I am Hugh Spitzer, Project Manager of Asbestos Products at CPSC. We will proceed from the presentation given by Steven Koehler in the Work Session on Gaskets and Packings. You have received an agenda listing questions around which we want to center our discussion. I will not go question by question, but there are topics I do wish to cover. Also, you may have questions on materials that Steven Koehler did not cover. And lastly, and most importantly, I want to address the health and environmental effects of the substitutes.

Hugh Spitzer asked if there are gaskets and packings made from any other materials other than those mentioned by Steven Koehler in his presentation on gaskets and packings.

Steven Koehler of Green Tweed Packing Company said that a few substitute materials that he did not mention in his speech were fiberglass and ceramic fibers, each bound together with teflon suspensoids--Mylar© is the copy-right name. Fiberglass, however, is too abrasive and brittle for use as dynamic pump packing.

John Arena of Combustion Engineering said that in the first question on the agenda you state that gaskets are impregnated with a lubricant. He said his company manufactures a rope gasket which is 100 percent fiber, with no lubricants or other additives, as it is intentioned for static service.

Steven Koehler said that is correct. The first question we address this afternoon should be on uses of fibers. Ceramic wicking is one such use. They are for basically static service-door gaskets, etc.

Bill Timmons of Celanese Corporation said that Celanese has just begun to market a fiber. Preox (PAN) is an intermediate material which is available commercially. The main cost factor in the production of carbon fibers is a 50 percent yield loss. The fibers produced from these intermediates have no yield loss, which therefore reduces the initial production cost disadvantage.

Preox is a precursor to a carbon product. Bill Timmons addressed a question on brittleness saying that these fibers have over 10 percent elongation. Next, he was asked about the fibers' behavior in response to ranges of temperature. He responded that the conversion to carbon begins around 300°C, with a corresponding change in volume.

Steven Koehler asked Mr. Timmons to define Preox. Mr. Timmons replied that the carbon fibers currently used in packings are based on rayon precursors, which have only a 20-30 percent yield. With Preox, Celanese uses the fiber itself (trade name Celiox), therefore, loses less in the production process. Polyacrylonitrile precursors (PAN) would result in a 50 percent carbon yield. These intermediates have a six member ring cross-linked ladder structure.

Hugh Spitzer asked if he had any literature on this material. Mr. Timmons replied that he did not have it with him but could get it that day or the next day.

Ted Merriman of DuPont de Nemours Company, Textile Fibers Section thanked Steven Koehler for discussing Kevlar® in packings. Dr. Merriman discussed Kevlar®, saying that it is an aramid fiber which is now used in noncontinuous forms in gasket replacements and other asbestos uses. Kevlar® pulp, produced in a process similar to wood pulping, results in a slurry material with short fibers of random length. This material is amendable to use in wet or dry processes. Typical beater-add applications are a natural for this material. Kevlar® is generally considered to be expensive. However, the pulp is priced at around $3.75 per pound, a less drastic difference from the cost of asbestos fibers.

Steven Koehler asked if Dr. Merriman knew about Kevlar® in heated water under pressure. He asked if there were any known problems with breakdown of tensile strength at, say, 300°C.

Ted Merriman said he had not done experiments with 300°C water. They have used 212°C water with no breakdown. Kevlar® begins to breakdown at 400°C, through irreversible oxidation. The products of degradation depend on the process; i.e., conditions of degradation; mostly carbon is produced. Any other products are proprietary information. When Mr. Koehler asked about the likelihood of glassification, Dr. Merriman replied that Kevlar® does not sublime. When asked about possible volatility of Kevlar®, Dr. Merriman replied that there are volatile products of the degradation process. When asked if the pulp process is a shearing process in water, Dr. Merriman replied that the process is a standard papermaking technology. He said that if it works for wood products, it will work for Kevlar®. He said that he represented the Kevlar® Research Group in Maryland and the Wilmington, Delaware Chestnut Run

Site. When asked about pH, Dr. Merriman replied the Kevlar's® sensitivity to pH may limit its use as a substitute for asbestos-cement pipe. He said they have not determined pH ranges yet.

Steven Koehler said that they had identified Kevlar® pH range as between 3 and 11. However, compression of the material may increase friction, heat, and therefore, wear on the material. This in turn would increase any degradation that may be caused by the presence of acid.

Ted Merriman said that it depends on whether you are in a high shear environment or not. Steven Koehler agreed, saying that pH ranges can depend on the pressure involved.

John Zeitz of the Victor Division of Dana Corporation said that the volume of this segment of the industry is in service gaskets. He disagreed with the assumption that there are technical substitutes for gaskets in areas related to engine products. He said that one cannot predict that a new product will be usable in those uses especially in cylinder heads or service manifolds.

Steven Koehler said that the substitutes would probably function, but the question is whether the new product is cost-effective. There are available substitutes that can be used.

John Zeitz replied that substitute gaskets would have to be designed for each specific application and mentioned possible problems with load difference.

Bill Olden of Union Carbide said that they have graphite materials used for head gaskets that are flexible on any engine.

John Zeitz expressed doubts about the service of these graphite materials on new designs.

Mickey Hosmer of Jim Walter Resources said that they produce fibers at a cost of 25 cents per pound, much cheaper than longer fibers. John Zeitz asked about the length of these fibers. Mr. Hosmer replied that they have a 40-60 percent aspect ratio.

Gordon Yuellig of Proctor and Gamble asked how many substitutes meet FDA regulations for contact with food, drugs, cosmetics, and medical devices.

Steven Koehler replied, "One: Teflon®". Mr. Kelly said they have been trying for years to find components of packings that will meet with FDA regulations.

Al Diangelos said that Gore-tex, a PTFE fiber has also been approved; however, this is also a Teflon® derivative.

Mr. Yuellig asked what we would do when we need a material that has a temperature range above the 400°C range of Teflon®. Steven Koehler replied that possibly metal gaskets could be used. Mr.Yuellig said that that is a very poor substitute. (Later, he added that there are only temporary solutions.

There is no satisfactory metal packing.)

John Halberta of Carborundum said that they produce Grafoil®, a flexible graphite product. They said they are close to FDA approval for its use relative to food additives. They have one more hurdle (rat studies, etc.), which they hope to clear in one more year. Aramid products, too, might be approved if they are pushed.

Mr. Yuellig said that they had been trying to get rid of asbestos for years but the FDA has not revoked its use. Mr. Diangelos said that Dr. Kreska of the FDA is the man they have been working with.

Steven Koehler asked if we wanted to get rid of asbestos, but are not doing so.

Hugh Spitzer replied that there is sometimes a fear among the regulatory agencies that in banning one product, you unleash a worse product on the market.

Steven Koehler asked if asbestos has to pass standards such as those the substitute must pass.

Hugh Spitzer asked, other than technical and FDA specifications, what specific needs and performance standards do you have to meet?

John Zeitz replied that for temperature they need a standardized ignition loss test which ASTM (The American Society for Testing and Materials) can provide. They will be buying temperature resistance with this substitute. It functions satisfactorily in the 600-800 (possibly to 1000°C) range.

Thomas Jackson of Johns-Manville Corporation said that there is an existing standard now that goes up to 1500°C, which is now being revised; whether it is adequate or not is unclear.

Al Gordon of Federal-Mogul Corporation said, regarding performance standards and material specifications, ASTM is an agency operating under a voluntary set-up. ASTM promulgates both material specifications and test methods. F-8 is the Committee on Gaskets. Most standards are methods of testing, also spelling out physical and certain functional properties. In addition, a classification system is used to determine the appropriate specification. Virtually all deal with non-metallic and non-rubber materials. (D-11 is the Committee for Rubber Materials.)

ASTM was started at the request of the government, to develop standardization. It is concerned with environmental issues. There may be an opportunity for coordination: Any asbestos replacement materials would fit into the classification system. If not, provisions have been made to allow for incorporation of new materials. SAE (Society of Automotive Engineers) engineers use ASTM's standards rather than duplicate their work. The military also has a system set up to parallel ASTM's classification.

Ted Merriman added that there is a military specification for graphite: 24503.

Steven Koehler said that there are military specifications for most graded packing materials. Teflon filament, for example, is MIL-P-24377. One problem here is that when the military asks for bids, they specify materials, and will not accept substitutes. Someone said that there is now a concerted effort in the Navy to get rid of asbestos.

John Zeitz said that the military is very slow here. In some cases, they ask for asbestos.

Hugh Spitzer asked if those specifications spelled-out asbestos materials only.

Steven Koehler said that performance characteristics are specified as well. Some military specifications require asbestos; and these will probably be the last to change. They purchase a lot of asbestos.

Mr. Yuellig said that substitution for asbestos means diversification. Asbestos was so versatile. Using flax again is a regression; it is corrosive, and does not function well at extreme temperatures.

Steven Koehler said that for pumping applications, long run, cost effective, over-engineered, substitutes exist.

John Halberta said that they have a substitute and they would hate to have to compete with flax.

John Zeitz said that they may be able to get more materials into the market places. Finding direct substitutes is a minimal goal, although it will not look so for the next five years. It will look like a snowstorm.

Steven Koehler said that when asbestos was discovered to have so much versatility in its gasket and packing applications, some reliable old stand-bys were overshadowed. He estimated that some 40-60 percent of asbestos uses were unnecessary and were used simply because they were convenient.

Ted Merriman said that is the very point. Without much technical background, the average mechanic knows about asbestos and knows it will work. I agree that if you over-engineer with graphite, everything will work out.

Mr. Yuellig said if you are a small businessman without extensive technology, asbestos is so versatile that it works for just about any need you have. It will take a lot of good material to replace it, with the exception of food products.

Louis Blecker of GAF Corporation asked what the health risk of asbestos was. He asked how much exposure there was and does it warrant all this cost. Hugh Spitzer replied that this workshop is concerned with substitutes for asbestos. Louis Blecker asked if we needed asbestos substitutes. Hugh Spitzer replied that we are gathering information to find this out. Louis Blecker said then why not use scientists, and competent people to study the problems in a noncompetitive, nonadvocacy setting. Hugh Spitzer thanked Mr. Blecker for his comments.

Herb Posner of NIEHS (the National Institute for Environmental Health and Safety) said that they are looking at a number of real world situations (brake linings, hair dryers, and so on) where there is an opportunity for asbestos exposure. He said there is good evidence of the hazards of asbestos. He said that as he saw it, the purpose of this conference is to identify where exposure occurs and substitute asbestos with less hazardous substitutes. He expressed concern that the health aspects of asbestos are always last on the agenda, but acknowledged that perhaps that was alright because there was a day and a half of health sessions scheduled.

Gordon Yuellig said he had a question for Mr. Posner. He said that everything he had read, including Dr. Selikoff's study, stated that everyone who has been exposed to asbestos was affected long ago. He asked how the health hazards of asbestos exposure from hair dryers, et al, could be correlated with exposures from the asbestos industry.

Herb Posner asked how long have hair dryers been used. Ted Merriman asked how much asbestos gets out from these hair dryers. He said that GE (General Electric) went along with the hair dryer recall because of adverse publicity but later studies showed few, if any, fibers get released.

Herb Posner said that asbestos-cement sheeting, when misused in schools, creates an exposure problem.

Derek Kuhn of the Richard Klinger Corporation said that he knew that only substitutes are to be discussed, but asked if we could distinguish between friable and encapsulated asbestos here.

Hugh Spitzer replied that he would prefer to limit discussion to substitutes for asbestos.

Derek Kuhn asked if there was any overlap when you consider encapsulated asbestos hazards as compared to the friable non-asbestos fibers.

Hugh Spitzer said that it is not appropriate to discuss asbestos issues now. He said the purpose here is to gather information on health effects, etc. of other materials.

Herb Posner asked about uses of asbestos in gaskets and sealants. What about workers who are exposed during servicing and installation? Someone replied that that is not for this forum and the group should stick to discussing substitutes.

Hugh Spitzer said that perhaps they should go to the health effects studies. He asked what results FDA (the Food and Drug Administration) had been getting from their studies.

John Halberta referred to Grafoil® gaskets in his reply. He said that his company (Carborundum) had to do carcinogenicity studies, and that their results showed no effects on rats. For PMAs (polyaromatic hydrocarbons), they have to demonstrate a concentration of 2 ppb or less. He said that the sensitivity of the test had been the major difficulty in analyzing Grafoil® for the presence of PMAs. He said they could not find PMAs in flexible graphite, so it was treated and then analyzed for PMAs. (No animal tests were done.)

Hugh Spitzer asked if asbestos has been shown by the FDA to meet the 2 ppb hurdle. He also asked how this standard was set.

A participant replied that FDA set the 2 ppb standard.

Hugh Spitzer said that one problem with comparing asbestos to an organic substance is asbestos is for all practical purposes not metabolized. Asbestos can stay in the tissue, while other substances can be metabolized and excreted.

Malcolm Fenton of Marrietta Resources International, Ltd. said they manufacture Suzorite mica. He said when they tested a hypothetical process and product for health effects, the data would necessarily be outdated within five years time. By then, the use and exposure would be different. He asked what the Federal agencies expected from health studies on substitutes.

Hugh Spitzer said that answer would be "safe material". Let me elaborate--regulatory agencies depend on scientific reports in assessing any chemical or product with respect to health effects. Animal bioassays, epidemiological studies and in vitro testing are all of value.

Malcolm Fenton commented that Bendix has spent millions of dollars on health research; a development which is good both for the American people and obviously for their company. He said that the job of the government was to make sure that all brakes in the U.S. work. He asked if there was (any possibility of) a bill in Congress to give companies like Bendix a tax break on such work. He also asked about possible tax breaks for small companies.

Hugh Spitzer commented that there is a National Toxicology Program (NTP) which recommends material to be tested. One criteria for material to be reviewed by the NTP is large production/use volume. This is an established program available out of NIH (the National Institute of Health) coordinated with CPSC, EPA, and FDA. The government is concerned with industry concerns.

Malcolm Fenton said he assumed, then, that if a material is widely used, it can be evaluated by government methods. He also asked about material not yet widely used (which you would like to have widely used).

Hugh Spitzer replied that he should talk to the agencies to try to get into a testing program. Herb Posner said that NTP is already trying to get thousands of chemicals into at least short term tests as a start.

Hugh Spitzer said that his advice was to keep after the agencies. He suggested that companies should try to get chemicals into the testing program. He continued by asking for information on the kinds of tests of materials which are underway or planned (by industry).

A participant suggested to Hugh Spitzer that one of the other considerations is energy requirements from producing and using these substitutes.

John Halberta commented that the silence indicated a general lack of knowledge on testing. He indicated that participants (from industry) were being asked whether they had done work on a product that might or may not be acceptable by the government. He said that no one has any experience in getting products approved. (Also, the economies of scale for asbestos replacement are not yet well understood. However, asbestos replacement presents us with a marvelous opportunity, however elusive it may now seem.) He said that (the government) had many definitive questions but that they could only supply vague answers.

Hugh Spitzer asked for best guesses as to the needs of companies.

John Zeitz replied that they might require a multiplicity of systems, but they would not have to start from scratch. Existing equipment will not be thrown out as boat anchors.

A participant commented that the manufacturers of substitute fibers should be asked that question, not the users. Someone commented that capitalization for substitutes right now is not great.

John Halberta said that the question is whether you will have significant enough incentives (e.g. tax incentives). Without incentives, new technology will not be developed.

Louis Blecker said that they have just built a glass plant; there is a tremendous need for capital.

Ted Merriman said that most of the emphasis this afternoon has been on fibrous substitutes. Nonfibrous replacements will be important, too.

John Halberta said that their product, Grafoil®, is nonfibrous. Production may require new capital.

Hugh Spitzer asked if there were any further comments on nonfibrous substitutes.

Frank Fry of Hollingsworth and Vose replied that the pressure will work backwards from the user to the fiber supplier, each trying to conserve capital. The incentive for change will come from the end users.

Hugh Spitzer said thank you very much for coming this afternoon.

SUMMARY OF THE ROUNDTABLE DISCUSSION ON SUBSTITUTES FOR ASBESTOS IN PLASTICS AND FLOORINGS

PANEL MEMBERS

Gale Wyer -- (Moderator), CPSC

Terry Karels -- CPSC

Will Stelle -- EPA, Office of Pesticides and Toxic Substances

The meeting was attended by 20 to 30 people. The two hour session was divided into two portions: the first on plastics and the second on flooring.

PLASTICS

The success of the search for substitutes for asbestos fiber depends upon the function of the asbestos in each particular product and product category. Asbestos fibers provide good tensile strength and possess good thermal resistance. In addition, they also serve as a cheap filler for plastic mixtures and make them easier to mold and to work. Many fillers are available that are cheaper than asbestos but do not possess the same strength or heat resistance.

If the thermal insulation or tensile properties of asbestos are necessary, replacement may require using several materials together, such as a mixture of mica and an organic material. If these special properties are not necessary, organic fillers may be used, which are often cheaper than asbestos.

It was also noted that man-made fibers are generally more expensive to produce than refined asbestos. Substitutes, especially man-made materials are not as permeable as asbestos, to chemical constituents such as dyes. Different, possibly more expensive means of production, could be necessary when man-made fibers are used.

Manufacturers are often looking for products with greater reinforcing and insulating properties than asbestos; this is due to increased demand for high-performance materials by industrial users.

One view was that unless the use of asbestos is banned that it will continue to be used since the product is effective and cheap.

Other views were that consumer pressure would eventually drive manufacturers away from asbestos and that this pressure was preferable to an outright ban because the latter would cause serious economic problems for the industry. An example of this pressure is the increase in lawsuits. Aother example is the shift away from asbestos use in hair dryers suggested by CPSC.

One participant questioned the health hazards caused by using asbestos in plastics and also stated that, regardless of the actual risk, the market was demanding plastic products that did not contain asbestos fibers. Consequently, he stated, the industry desired to move to substitutes where such substitutes were available.

Eula Bingham of OSHA was represented as saying that there is a substitute for every application of asbestos. Attendees argued that defense and national security reasons could be used as reasons for continued use.

Participants said that an imposition of a ban would harm the industry. Larger firms may gear up for substitutes; smaller firms may not be able to gear up. Smaller firms cannot afford to tie up capital for research and development and may be driven out of business.

A suggestion was made that CPSC and EPA contact plastics and other professional organizations and associations for further information. Two participants cited as a useful compilation of substitute information a recently published book, Handbook on Fillers and Reinforcements.

FLOORING

Asbestos is used as reinforcement in vinyl asbestos (V/A) tile and as a backing in vinyl sheet. The lengths of fibers used in each application are different: the backing uses longer fibers, while V/A tiles use shorter fibers.

Nothing more was discussed; members said that the industry is very secretive and will not share technology. There are tremendous costs involved in research and development for substitutes, and the firms will not share expenses. Further, the firm that finds an acceptable substitute "stands to make a lot of money" and may end up controlling the market.

Because no one was willing to speak about flooring, the attendees were encouraged to submit written remarks.

SUMMARY OF THE ROUNDTABLE DISCUSSION ON PAPER AND ROOFING PRODUCTS

PANEL MEMBERS

Suzanne Rudzinski -- (Moderator) EPA, Office of Pesticides and Toxic Substances

David Bailie -- Koppers Company

Nancy Roy -- GCA Corporation

Christine Spadafor -- EPA, Office of Pesticides and Toxic Substances

June Thompson - EPA, Office of Pesticides and Toxic Substances

In response to a question by Ms. Rudzinski asking if there were any uses of asbestos paper products for which there are no known substitutes, Mr. Huseby, General Electric (GE) described an asbestos paper tape used in GE transformers for which GE is seeking a non-asbestos substitute tape. Ms. Carol Mansfield, Carborundum, then proceeded to describe her company's line of ceramic fiber papers, their characteristics and cost range, claiming Carborundum's paper line is economically competitive with asbestos paper.

Ms. Rudzinski inquired if any representatives of aramid or ceramic paper manufacturers were present. Carol Mansfield (from Carborundum) indicated that she and a representative of Babcock and Wilcox were present.

Mr. H.B. Kinsley added that James River Paper Company also makes a line of ceramic papers.

Ms. Rudzinski next directed questioning to what in the way of performance characteristics is lacking in substitutes.

Mr. Beto, GAF, stated that (for flooring) his company knows of no direct asbestos substitute which is an economical, high performance, fire resistant, noncombustible material. Mr. Beto went on to say that there is no single substance (listed on the summary handout of substitutes) that does not have some deficiency when compared to asbestos. Also, when one looks at the economics, there is no good replacement.

Mr. Beto, in response to a question about GAF's ability to find suitable substitutes, stated that his firm is spending hundreds of thousands of dollars trying to find substitutes.

Ms. Rudzinski asked about the cost differential between fiberglass-containing and asbestos-containing products. Mr. Waldman of International Paper Company said that the question cannot be answered directly because of price differences between grades of asbestos.

Mr. Kinsley of the James River Paper Company stated that Hercules has been working on their lexar fibers and that they presented a paper on the process within the past year.

Ms. Rudzinski asked if there are any applications (for paper products as well as for roofing products/coatings) for which there are no acceptable substitutes.

George Odean of DuPont responded that in the line of specialty papers, there is no direct substitute for asbestos membranes in certain electrolytic cells. DuPont manufactures a line of asbestos-free membranes, Nafion, for some elctrolytic diaphragms but it is not a direct substitute for the cells that now use the asbestos membrane. In order to use the Nafion membrane, the existing cells have to be replaced.

A representative of the Chloralkali Institute stated that the substitute represents companies which manufacture Coroden® and that 75 percent of the use is for diaphragm cells. He stated that asbestos is used with the diaphragm material and that there are no substitute membrane cells.

An estimate of 2 billion dollars was given for the conversion from asbestos to substitute material in the chloralkali industry.

In response to a question about what type of properties would be required for a suitable substitute for the asbestos membrane cell, the Chloralkali Institute representative stated that he did not want to address that at the present time.

Mr. Edmond Berrigan of DuPont Industrial Fibers Division stated that he wanted to describe fibrous asbestos replacements which DuPont is developing called Kevlar® and Nomex®. They are continuous filament aramid fibers. The fiber is used as reinforcing material for a number of applications, especially for paper uses. It is economically competitive at a cost of $3.75 per pound for the pulp. Like asbestos, fibrous material has desirable characteristics such as high tensile strength. The fibrous pulp material has releasable fibrils with aspect ratios in the respirable size range. Mr. Berrigan went on to say that this fibrous material is well suited for applications like paper because it is made by paper-making processes. However, the material can also be used for other products such as beater-add gaskets or friction paper. Because the cost is high by asbestos standards, Kevlar® pulp is obviously not a direct substitute for all asbestos in paper products; however, it can replace a small quantity of asbestos. Also, there are some applications, such as for gaskets and friction paper, where it is economically feasible to use higher priced fiber like the Kevlar® pulp.

In response to further questioning, Mr. Berrigan indicated that there are definitely fibrils of inhalable size that can be released from the Kevlar® pulp, but that it is very difficult to get the fibrils out of the material. The exact number of fibrils that are releasable is not known, but it is a very small percentage of the total. However, DuPont has addressed the problem of the inhalation toxicity of aramid fibers. A paper presenting preliminary results of an inhalation study will be given in the Health Effects Session. To date, there is no evidence that DuPont should not continue to develop production of these aramid fibrous materials.

Vance McCarthy (a reporter with a Mineral publication) brought up the question about what guarantee is there that people who invest in research for asbestos substitutes would not have to replace the substitutes later on after they are tested.

Members of the panel asked that questions associated with health effects of substitutes be deferred to the Health Effects Sessions.

Mr. Stimola asked that the group address a second question; what fibrous product substitutes exist in the protective coating product field? In the category of protective coatings, Mr. Stimola indicated that his firm knows of no effective substitutes for asbestos even if they disregard economic considerations. Although their firm is familiar with many products offered as asbestos substitutes, in their opinion the substitutes do not work as well as asbestos.

Jim Palmer, MiniFibers, stated that his company has a high density polyethylene fibrous coating formulation that he has been working with for about three years.

There are about 16 formulations for protective coatings, rib coatings, etc. The fiber itself is called the "130380" and is economically competitive with asbestos.

In response to a question about the material's degradation by mildew, etc., Mr. Palmer responded that he was not too familiar with that aspect of the product, but that he would give the questionner some literature.

Another participant (unidentified) stated that he would be speaking for the roofing industry concerning substitutes for asbestos fiber. He indicated that his firm has worked with MiniFiber's product and does not find it to be a viable substitute for asbestos regardless of cost.

In response to Ms. Rudzinski's question as to what reason his firm finds that the MiniFiber product is not an acceptable substitute, the unidentified participant stated, for one thing, they could not keep it from settling. Also they had found it to be a fiber that burns and does not provide body to the coating material.

A question was addressed to the chair about what EPA and the Office of Toxic Substances thinks of synthetic organic fibers. The question about fiber size was deferred to the Health Effects sessions. Participants were asked to submit any weathering data that might be available.

The same participant raised doubts about synthetic fibrous coating materials stating that the use of toxic fungicides compounds the (possible health) problem. The staff invited the participant to submit any data he might have on fungicides' wear, etc.

Philip Battoli, GAF, stated that his company has been making roof coatings for 90 years. Mr. Battoli stated that unfortunately there are now no alternatives for asbestos for reasons already discussed.

Mr. Battoli stated he was not convinced that polyethylene or polypropylene fiber is suitable for an outdoor environment. For example, in such applications as flashing cement, a vital part of the roofing structure, these organic fibers might not be able to withstand ultraviolet light, temperature and other forces of nature as well as asbestos fiber could. Mr. Battoli went on to say that shelf stability of alternates is not as good as that of asbestos. There are also problems of premature failure and lack of proper reinforcement. So, if there is an alternate, GAF has not yet found it.

Also, GAF has not found suitable alternates for certain types of gaskets. Ceramic fibers may be useful in certain types of gaskets, but not for all. Head gaskets, for example, have different performance requirements than exhaust gaskets. Alternates for asbestos are being tested, but there is no assurance of long term performance. If a firm converts a tractor or pit asbestos gasket to an alternative asbestos substitute gasket, long term performance data are needed.

Next was a discussion between Dave Bailie, Koppers, Inc., and another participant about the use of one-ply asbestos-free membrane material for repair or replacement of existing roofing coating.

Ms. Rudzinski next asked if there were representatives of other paper products present -- pipe wrap, millboard, etc., who would like to address some of their substitutes and problems.

Ms. Mansfield of Carborundum stated that her firm has an array of millboards, some of which are made with inorganic fibers and some of which are made with organic fibers. In response to the question if Carborundum's millboard products will substitute for all asbestos millboard applications, Ms. Mansfield indicated "no", that she did not think anyone had a product that will substitute in all cases.

It is very difficult to compare prices of substitute materials with asbestos products, stated Ms. Mansfield. For paper, there are several grades, as well as low and high temperature paper lines. As for millboard, there should be no equipment conversion costs, since Carborundum carries the same sizes as the asbestos board now available.

Ms. Rudzinski asked if there were paper products other than for certain gaskets and the flooring already discussed for which there are no known substitutes.

Mr. Kinsley of the James River Paper Company stated that in the ten years since the company has been incorporated it has not made any asbestos-based products and has been looking for opportunities for non-asbestos products. However, there are areas where there do not appear to be viable or economical substitutes. Beverage filtration is certainly one of those areas.

A representative of Munson Products stated there are also roof coatings substitutes which will require equipment changes and very substantial capital expenditures.

Ms. Rudzinski next asked about substitute material durability.

In response, a participant indicated that where organic fibers are used as substitutes, they degrade whereas asbestos does not. So there is no comparability as far as durability with these types of substitutes. With synthetic coating materials, one has to use a germicide or fungicide to keep rotting from taking place. There is not yet enough experience with use of substitute materials to be able to determine how comparable they are with asbestos-based coatings.

The James River Paper Company representative H.B. Kinsley described some performance problems with a specialty paper their firm is trying to develop. With substitutes such as inorganic fibers, there can be problems with the crush test and with creep resistance. Also, even if the higher-melting temperature organic fibers do not creep, they probably crush. There is a need for resiliency and high temperature resistance.

Further discussion of the performance problems of substitutes followed.

One participant said that roofing systems being installed today are based on European technology. But durability of roofing systems in Europe really cannot be used for comparison of durability of roofing in the United States. Asbestos roofing systems have proven durability. Non-asbestos systems have not been out there under all services, conditions, and applications long enough for durability evaluations. Also, accelerated exposure/durability testing cannot be directly interpreted. It is like an engine running at idle speed. One cannot say, based on that, what the engine's performance will be at high speed.

Glenn Simpson of CPSC inquired about earlier references made to the fire retardancy aspects of asbestos in roofing mastic. Mr. Simpson stated that references had been made earlier implying that a roofing mastic substitute (for asbestos) would not be suitable because it was flammable. But, Mr. Simpson's question was whether the entire mastic mixture was flammable, whether or not it contained asbestos.

A participant replied that claims of fire retardance of asbestos in roofing coatings were not made, rather, the comments relative to roofing coatings were made criticizing their organic fibers which degrade on weathering, and their tendency to mildew, which degrades the whole product.

Asbestos fiber in an organic vehicle in the coating does degrade. The speaker stated that his firm's organic fibers placed in that same organic vehicle no longer contribute to the weatherability of the coating. In fact, if the coating and fiber is mildew resistant, it detracts from the weatherability of the coating.

Another participant stated that the use of asbestos in asphalt does provide a great measure of fire resistance. A discussion of the characteristics of asbestos-based asphalt follows in which the speaker reiterated that asbestos-filled asphalt coatings are weather and fire resistant.

Ray Lawson of Southwest Petrochemical Division, Whites Chemical Company stated there is a difference between resistance and retardance. Lawson recited the military specifications for automotive undercoating on vehicle undercoating. For an asbestos-containing asphalt coating placed in a flame, it has to extinguish itself within a specified period of time (20 seconds or so) after the flame has been removed. With an asbestos-containing coating, the flame will estinguish itself. With synthetic or organic fibers, the flame will continue burning. Mr. Lawson said that is resistance, not retardance and there is a difference.

Ms. Spadafor asked questions about tests for substitutes -- were there observed differences in energy requirements for processing substitutes versus asbestos products? Ms. Rudzinski added a question about whether observed differences in energy requirements would be a controlling factor in a decision to go with either one or the other.

Sam Elwood of H.B. Filler stated that for most of the substitutes his firm has looked at, it takes a lot more energy to try to get products of uniform consistency. When one is running a 125 hp motor 20 to 30 minutes longer (even up to 1-1/2 hours longer) to get a uniform mixture, considerably more energy is being used than when asbestos is being used. On energy consumption, this is almost economically unfeasible.

A few other comments were made concerning the differences in energy requirement between substitutes and asbestos-based products.

Since there was no response to Ms. Rudzinski's question if there were any other points or questions to discuss, the meeting adjourned.

SUMMARY OF THE ROUNDTABLE DISCUSSION ON SUBSTITUTES FOR ASBESTOS TEXTILES

PANEL MEMBERS

Alan Carpien -- (Moderator), EPA, Office of General Counsel

Bob Liss -- EPA, Office of Pesticides and Toxic Substances

Sam Manfer -- Carborundum Company

Dave Mayer -- EPA, Office of Pesticides and Toxic Substances

Alan Carpien suggested that the group center its discussion on the technical performance of substitutes, and their lifecycle costs. He also suggested that Sam Manfer of the Carborundum Company lead the discussion. Mr. Manfer invited the group to bring up information on a variety of substitute areas, since his expertise involved ceramic fibers.

Rick Hettich of Amatex pointed out the distinction between fire resistent and flame resistent textiles. Fire resistent means that the textile will burn when a flame is applied, but will self-extinguish when the flame is removed. Manfer pointed out that there are different forms of ceramic materials. Some are flame resistent, while others are fire resistent. He said that they will remain inert in either case.

Phil Wagner of DuPont added that while Aramids are self-extinguishing, flammability may be relatively unimportant. Sometimes whether or not a textile is a good thermal barrier is the only important criteria.

Mr. Kennedy of Raybestos stated that chemical resistence was important in the manufacture of chlorine. He said that many different fiber types had been tried, but that no appropriate substitute had been found. Mr. Manfer added that other chemicals needed to be tested.

Sam Manfer wanted to get back to the question of fire resistance. He asked the group whether the leached silica fibers were effective above 1000°F. Al Weiner of the Navy Department said that the terms self-extinguishing and non-burning were not meaningful. He stated that some sort of standard test was needed. Manfer asked whether these specifications were indicative of the applications. Weiner stated that the CG test has been used to try to indicate this, since no weight loss is the ultimate test of fire resistance.

Joe Sonatol of Pittsburg Corning suggested that the group center on specific product applications. By generalizing, many cases in which fire resistance is unneeded would be discussed. It was decided that the list of applications in question 1 of the agenda should be looked at.

The first item was welding curtains. Bal Dixit of Newtex added that the type of asbestos fabric must be specified. Commercial asbestos with 30 percent rayon may burn under certain conditions.

Bob Liss asked whether there were specifications for welding curtains. Mr. Manfer replied that welding blankets have specifications, but that they may be made from a variety of materials including PVC, rubber, etc. Some of these materials have been known to off-gas and produce cyanide. Lyle Cohen of Magid Glove Company stated that specifications are up to the manufacturer. Alan Carpien asked whether there were reasons for using one material over another. Mr. Manfer responded that curtains were an open area, in that user preference is important. Welding blankets must withstand molten metal puddling. Asbestos has been the only material thus far to pass the military specifications. Mr. Weiner disagreed, and stated that high temperature silica products are actually better than asbestos, have a higher temperature capability and, depending on abuse, are as durable as asbestos.

The next product line discussed was welding blankets. Mr. Manfer stated that leached silica is effective, and asked whether any other materials were known to be effective. Mr. Dixit added that there are many non-welding applications for blankets such as covering machinery. Artie Bower of Gentex stated that Preox, Celiox Fiber is effective against molten metal splash. The cost of this material is $18-20/yard. It is generally effective in uses where there are short exposures to high temperatures, but not in long term, high temperature exposures.

Don Johnson of 3M noted that Nextel (a 3M product) when used as a hybrid has not passed the military tests. It was suggested that the group focus on a discussion of the cost-effectiveness and end-use specific considerations of various fibers. Alan Carpien then discussed the requirements necessary for a finding on "unreasonable risk" which EPA must support for each regulation of a toxic substance.

Bob Cordick of Araco stated that fiberglass is acceptable in textile applications where temperatures are 1000°F, up to 1800°F. It begins to weaken at temperatures of 700°F, but has been used for applications in which asbestos has not been moved. Silica cloth is also available for uses in temperature ranges of 2000-2300°F. The cost is dependent directly upon application. In some applications, it lasts six times as long as asbestos, yet costs only twice as much as asbestos. There may be additional economies involved through energy savings. In steel mills, high temperature textile applications have cut energy costs drastically. Al Weiner pointed out that several other parameters reduce the temperatures that textiles can meet. Steam, vibration and, refractory temperatures, all effect the durability of textiles.

Phil Wagner of DuPont stated that Nomex, Kevlar, and Teflon were all asbestos replacements. Their costs range from $5-$32 per pound versus approximately $.25 per pound for asbestos. These materials may be spun of conventional equipment. When Dupont markets these products, they use a system called the value-use system. This basically involved defining the exact use for a customer's product. Producing expensive substitutes can be cost effective if they are produced quickly, and in bulk. Also, if the materials are light weight (a small amount goes a long way), abrasion resistant, and have increased longevity over asbestos, they can be sold much easier. Also, these materials are rarely used alone but generally as hybrids. Kevlar and Nomex are aramids (nylons), they are high temperature resistant, flame resistant, and have no known melting points. They will off-gas at 800°F, depending on time and atmosphere.

Bal Dixit said that their main product, Zetex, is a fiberglass textile. A representative from Celanese, Bill Timmons, stated that they produce "Preox". This is a thermally stabilized polyacrylonitrile. It carbonizes at high temperatures, is not electrically conductive, and has good water absorption properties. Additionally it is quite flexible, but emits cyanide gas at 800°F. It will not support combustion in air. Alan Carpien asked for submission of additional information on this product.

Sam Manfer stated that while asbestos is replaceable, technical material on its substitutes provides little information on the application of substitutes. Alan Carpien responded that the Agency would like to get the best data possible for decision making. He called for submission of all substitute data which could aid the Agency in this endeavor.

Lyle Cohen of Magid Glove Company criticized all gloves. He stated that asbestos gloves are used only where they are necessary. They are big and clumsy. Replacements for asbestos gloves are not good either. Kevlar failed, and Zetex is too expensive. Al Weiner stated that gloves using a Kevlar and leather combination have been used successfully. Bill Myers of Amatex cited a study by Nottick Laboratories on safety clothing which showed that Kevlar did not hold up in some cases. Mike Wright of the United Steel Workers Union stated that steel workers were satisfied with the replacement gloves. He noted that in many cases a specific process should be examined. Often workers could be less involved in high temperature processing. Sam Manfer questioned the use of other fibers in gloves. Bal Dixit said that other fibers could be used if time was allotted to develop substitute products. Alan Carpien asked how long this development process would take. Sam Manfer replied that time was directly proportional to the pressure industry felt to develop substitutes.

Kathleen Gaillner of Koppers Company said that no substitute had been found for coke oven door jambs. They require materials which are flexible and can withstand temperatures of 2000°F. She added that the aluminum industry had also been looking for substitutes, but had not located them. Mike Wright suggested that if a company let it be known that they required specifications for an end-use, a substitute could be found. A representative of Dupont responded that simply looking at end-use may not be enough, because often the product and/or the application change. He estimated a time frame of about 3 years to develop a substitute for an application of this sort.

Al Weiner stated that the Navy had decided to use non-asbestos products where possible. Jack Reed of Amatex said that his company had a textile product which is rayon treated with phosphazine. It decomposes at temperatures of 400-500°F. It will burn, but extinguishes when the flame is removed. It costs approximately $3.50 per pound.

For electrical insulation, Bal Dixit reported that Zetex was adequate for thermal and electrical insulation. It has a lower (less than one-half of the time) thermal conductivity than asbestos. Dupont produces Nomex which is limited to 220°C.

SUMMARY OF THE ROUNDTABLE DISCUSSION ON SUBSTITUTES FOR ASBESTOS-CEMENT SHEET

PANEL MEMBERS

Dale Ray -- (Moderator), CPSC

David Cogley -- GCA Corporation

Elliot Foutes -- CPSC

Hope Pillsbury -- EPA, Office of Pesticides and Toxic Substances

Dale Ray of CPSC and Hope Pillsbury of EPA opened the discussion with a brief background description of the purpose of the roundtable discussions. David Cogley of GCA Corporation also invited comments on GCA's Summary Report on Substitutes for Asbestos, which had been distributed to participants. The following is a synopsis of the discussion on various points.

Dennis Kelleher and Sid Speil of Johns-Manville* had comments on the Summary Report on Substitutes. They asked what level of the supply chain the cost figures were for, in Tables 10 and 11. They commented that the figures were misleading and offered to supply the correct figures. John Jones of Cem-FIL and Frank Fekete of GRC Corporation also offered to supply corrections to the figures.

Michael Vaudreuil of ALCOA wanted information about asbestos-free marionite. He commented that ALCOA has found that asbestos-free marionite was a feasible substitute for asbestos-containing marionite, except in the largest diameter mold sizes, for which the asbestos-free product degraded more rapidly. Representatives from Johns-Manville asserted that all non-asbestos products degrade more rapidly than substitutes.

A.R. Frederick of General Electric commented that his company uses A/C sheet, in thicknesses of ¼"-2", for electrical boards, circuit breakers, etc. A/C sheet is used because it is strong, and has high electrical and heat resistance.

Representatives from Johns-Manville said that flat A/C sheet is used in schools and residential buildings. They also said that fiberglass-reinforced plastic, in corrugated sheet form, can be used in cooling towers. They said that glass-reinforced concrete (GRC) is less wind-resistant than A/C sheet.

John Jones of Cem-FIL described GRC. It contains glass fibers from ½"-1½" long. They are uniformly distributed in the matrix. A variety of fillers can be used in this product. Typical ingredients are Portland cement, marble dust, and glass fiber. GRC can be used outside for siding and other weather-resistant uses.

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* Hereafter called representatives from Johns-Manville.

Representatives from Johns-Manville asked Frank Fekete (of GRC Products) and John Jones to supply design figures and ultimates for GRC. John Jones replied that GRC can be used in place of most applications of A/C sheet. GRC's machining characteristics are not as good as those of A/C sheet; although GRC can be drilled and bolted it tends to chip. Its heat resistance is not as good as that of transite, which is produced by Johns-Manville. Portland cement which is used in their standard GRC products, dehydrates at temperatures higher than 500°-600°. Now Cem-FIL is working with high-aluminum cement (refractory cement). It has been tested to 1000°F. Transite is good at 600°F. John Jones also noted that their Portland cement product has only 5 percent fiber, as compared to A/C sheet which has 12-18 percent fiber.

Representatives from Johns-Manville asked John Jones about the strength-aging effect. They stated that they had information that glass in cement deteriorates after 5 years. They asked if this had improved?

John Jones replied that his company has field data showing the durability of GRC over 12 years. It starts out with a strength of 4,000 psi, and stabilizes after 4-5 years at 2,000 psi.

Representatives from Johns-Manville said they had information that the limit of proportionality for GRC is about 1200 psi. John Jones replied that GRC has been tested in the tropics, in temperate zones, and in the desert, by Pilkington Brothers in conjunction with the British government. The original GRC showed that the 28-day strength was 4,000 psi and the strength after 4-5 years was 2,000 psi. The improved GRC now has a long term strength of 3,000 psi. Representatives from Johns Manville said that GRC weakened with time down to the strength of unreinforced cement. John Jones disagreed with the above statement.

Representatives from Johns-Manville commented that the limit of proportionality of A/C sheet goes up with age. They also commented that the design limit for GRC was 870 psi but that A/C sheet was about 1000 psi.

John Jones of Cem-FIL reported that Fiberglass-reinforced plastic is used in corrugated form in cooling towers. It is also used as a skylight in industrial buildings. It is stronger than A/C sheet, but flexes more.

John Jones of Cem-FIL noted that there are 2 manufacturers of GRC sheet. Thirty companies in the United States make other types of GRC products, but many of them, such as some of those manufactured for architectural uses, are not replacements for A/C sheet.

Representatives from Johns-Manville described cement-wood board. It is a cement product with a high wood content. Its high cellulose content absorbs moisture, thus the sheet tends to expand and contract a lot. Similar problems with expansion have been experienced with cellulosic roofing felt and other products with high organic content.

Cement-wood board is used for interior applications because it is light and flexible. It is similar to masonite except that it has a Portland cement binder rather than a resin binder. It is used in roof underlayment in countries with low supplies of wood. It has weathering characteristics similar to those of marine plywood. They also commented that cement-wood board, when used as fill in cooling towers, would ruin the efficiency of the cooling towers if the material warped. Cement-wood board used in one cooling tower in the northwest United States is now being replaced with A/C sheet. John Jones of Cem-FIL has supplied GRC for use as cooling tower fill, however not the GRC product which is made of Portland cement.

David Cogley asked if A/C sheet is prevalent in ovens, safes, and heaters? Has GRC been used behind wood stoves?

John Jones of Cem-FIL commented that GRC has been used around furnaces; though not necessarily the GRC made with Portland cement. This GRC is made with a refractory cement which has a light-weight filler, so that it does not explode with heat. The GRC made with Portland cement may explode if exposed to a rapid change in temperature. A/C sheet may also explode if it is not porous enough. GRC can be installed behind stoves if it is U.L. rated. Concrete Design Specialties in East St. Paul, Minneapolis makes GRC for use behind wood stoves. Energy Research and Development Corporation makes ceramic fiber board for the same use. One can buy it now through Johns-Manville (Ceraboard), Carborundum, and other companies. The cost of these substitutes is 2½ times the price of asbestos-containing millboard.

Representatives from Johns-Manville stated that GRC cannot be used in highly corrosive environments such as ceilings in paper mills, where there is much moisture. John Jones of Cem-FIL asserted that in those cases it is the cement that gives out. Representatives from Johns-Manville said that metal reinforcement cannot be used in the above environments.

Dale Ray of CPSC asked if there are any applications for which we are not close to an adequate substitute for A/C sheet? Hope Pillsbury added that laboratory table tops might be an example of such an application. John Jones of Cem-FIL said that there may be no comparable non-asbestos product for laboratory table tops. Slate exists but it is inordinately expensive.

Hope Pillsbury asked if any of the more expensive substitutes could become cost effective with economies of scale.

Representatives from Johns-Manville replied that A/C sheet is better than other products in terms of life cycle cost.

John Jones of Cem-FIL said that economies of scale with greater sales of GRC should lower the price of this material, although not to the level of A/C sheet, because glass fiber is more expensive than asbestos fiber. John Jones expects that the price of GRC could decline to within 20 percent of the price of A/C sheet. In Europe, a nonasbestos GRC sheet called Tak-board is produced at the same price of A/C sheet, but Tak-board is an inferior material.

Dale Ray of CPSC asked to what extent can existing capital equipment be used to produce substitute materials or products?

Representatives from Johns-Manville said that in Europe they have looked for substitutes for asbestos for 20 years. They also noted that existing machines used to make A/C sheet require flexible fibers in order to work.

The representative from the Suzorite mica association said that people are developing complex mixtures that can be run on existing machines. The Hatscheck machine is used most often, but the Fourdrinier and Magnani machines can also be used. The Magnani is used for corrugated board in Denmark. He also said that mica runs quite well through the machines. It has good drainage characteristics, therefore it has been able to substitute for crocidolite and amosite.

The representative from the Suzorite Mica Association said that a law has been passed in Japan requiring reduction of asbestos content in A/C sheet to 5 percent down from 12 percent.

In Denmark and Sweden laws have been passed banning asbestos. Viable substitutes have not been found for A/C sheet. Some work on a small scale but there are reproducability problems on the large scale. Many contain some asbestos.

Irv Huseby of General Electric said that his company is looking for a substitute for transite in arc-shoot applications. The modulus of rupture is 3,000-12,000 for that material. The substitute they are looking for must have a modulus of rupture of 7,000 psi on a 2" stand. It must also pass a 3-point bend test. A/C sheet can pass these tests. Someone asked if they had tried wollastonite. Irv Huseby said that it acts like a ceramic.

Lauren Choate of NYCO, a division of PMI asked what was the rupture strength before the wollastonite broke.

John Jones said that there are international building standards for A/C cement; spacing of supports, etc. You need freeze/thaw tests, hot/dry tests, hot and humid tests, temperate, and monsoon tests, etc.

Lauren Choate said that wollastonite is used in Denmark. It is not as good as asbestos. Use of asbestos will be banned after 5 years in Denmark if there is a suitable substitute.

The representative from the Suzorite Mica Association said that 85 percent of the roofs in Denmark are made with asbestos. In the war years asbestos was not available so they used wood fiber. After 5-20 years the performance of the wood fiber in the roofs was not as bad as expected. The expansion and contraction on these roofs was quite large compared with that of asbestos-containing roofs.

Barry Castleman, a consultant, listed patents which various companies had on materials which could substitute for asbestos.

Dale Ray asked to what extent existing capital equipment can be used to produce substitute materials or products?

The representative from the Suzorite Mica Association said that it costs $4,000/week to try a new substitute material out on an asbestos-cement machine. Full-scale tests are necessary because even a small-scale A/C sheet machine does not give you the correct information. The total cost of the tests was about $10,000 for one week. The equipment to do the job may be valued at several million dollars.

John Jones of Cem-FIL said that GRC has been made on a Hatscheck machine and a magnani machine. There can be problems because of glass' tendency to flocculate. GRC was not developed as a replacement for A/C sheet. It cost several million dollars to develop alkali-resistant glass. Just a few percent of this money was directed at developing asbestos substitutes. A lot more is applied to light-weight concrete substitution than to A/C sheet substitution.

A representative from Carborundum said that development of ceramic fiber board was not aimed at the asbestos-replacement market. Millions of dollars were spent on research and development.

Frank Fekete of GRC Products said that the capital equipment to produce GRC was brought to the United States from England. The equipment alone (not including land or property) cost 1½ million dollars.

Dale Ray asked if energy requirements would be changed substantially by switching to production or use of the nonasbestos material? Representatives from Johns-Manville said the ratio of energy use between producing PVC pipe and A/C pipe was 4:1. They also commented that glass fibers take more energy to make than do asbestos fibers. The representative from the Suzorite Mica Association said that mica requires $1.50/ton.

David Cogley asked if the autoclaving and drying time for A/C sheet required a lot of energy?

A representative from Johns-Manville replied that the more autoclaving time is used, the less drying time is required, and vice versa.

Barry Castleman, consultant, commented that Rafael Ramos Lacen has reported that polyurethane sandwich panel is used in various housing projects in Puerto Rico. It is used in interior and exterior walls. It is not covered with an aluminum skin in Puerto Rico and in other developing countries.

The representative of the Suzorite Mica Association said that polyurethane has extremely toxic by-products of combustion. If the cover is removed metal would tend to protect it, but if the plaster wallboard protecting it falls off, then urethane foam is exposed. This material is not a viable alternative to A/C sheet because of the fire hazard.

Irv Huseby of General Electric said that a fracture/toughness test was needed such as a 3-point bend test or other similar stress test in order to rate replacements for A/C sheet. These tests are done by ceramacists.

John Jones of Cem-FIL asked if those tests were of slow or impact loads? Impact tests are run by Cem-FIL.

Irv Huseby of GE replied that impact tests are a good first start. Slow fracture/toughness tests are also needed. At GE they have been able to replace about 10 percent of the uses of arc-shoots with a nonasbestos product. Polyester-pressed molding would not take the temperatures.

Supradur makes roofing shingles and siding out of asbestos cement.

SUMMARY OF THE ROUNDTABLE DISCUSSION ON SUBSTITUTES FOR ASBESTOS-CEMENT PIPE

PANEL MEMBERS

Richard J. Guimond -- (Moderator) EPA, Office of Pesticides and Toxic Substances

Arlene Levin -- GCA Corporation

Richard McAllister -- EPA, Office of Pesticides and Toxic Substances

RANGE OF APPLICATIONS

Three types of asbestos-cement (A/C) pipe were identified: pressure pipe for drinking water, non-pressure pipe for sewers, and square pipe for air ducts.

It was mentioned that at one time A/C pipe was used for food pipes.

Rectangular-shaped A/C pipe, made only in Europe and used as air ducts, were discussed. This pipe is very thick, and its diameter is wide; from 4" to 36" if not wider. It is air cured. Round air duct pipe is also available.

ALTERNATIVE PRODUCTS

PVC, cement, clay, steel and iron were identified as substitutes for A/C pipe. Mr. James Warden of the U.S. Water and Power Resources Services commented that in a range of up to 24 inches A/C pipe is very competitive with the substitutes, but above 24 inches the other pipes become competitive, and above 42 inches A/C pipe is not competitive at all.

Concrete pipe containing glass fibers was discussed as a possible substitute for A/C pipe. Mr. Joseph Jackson, representing the A/C Pipe Association, made the point that fiberglass, even the alkaline-resistant glass, does not maintain its strength in alkaline environments over long periods of time. The clay and glass silicates melt when autoclaved; therefore, fiberglass is an impractical substitute material.

The conclusion of this discussion was that substitutes for asbestos-cement pipe are not available in the form of substitute fibers, but rather, are available only as alternative products such as concrete or steel. It was mentioned, though, that a company is developing a wire pipe fiber in which about five of these fibers (each about an inch or an inch-and-a-half long) are glued together by a soluble glue. The soluble glue dissolves when the fibers are put into the cement, making it easier to handle. This is being tested for concrete pressure-pipe applications. It was also thought that a German company, named Eternit, was researching a new fiber that had the same properties as asbestos.

Concrete is used for pressure-pipe applications up to 150 feet a head, and diameters from 12 inches up to 132 inches. PVC, ductile iron, concrete, and steel are used for pressure pipe. Clay pipe is not used for pressure applications. Someone asked whether any pipe that was used for pressure applications could also be used in sewers. Someone replied that metal pipes would not be used in sewers because of the inversion process. It was concluded that concrete, clay, fiberglass, and plastic pipe could be used for non-pressure pipe. Someone said that plastic pipe had half of the market, however, when challenged, revised his statement to conclude that plastic pipe has a large share of the market.

Mr. Young Joe of Substitute Abrasion, mentioned a fiber containing 10-15 percent carbon fibers and also glass fibers or ceramic fibers, for use in pipes. Someone commented that they thought inclusion of carbon fiber would increase the costs of the pipe so it would be no longer marketable, but Mr. Joe said the fibers increased the cost of the pipe only slightly. He commented that the cost of the carbon fiber was in the $6-8 range.

Mr. Barry Castleman listed some patented fibers such as a cotton-reinforced center product made by GAF; a Japanese patent from Asahi Glass Company, which is a reinforcing material for cement sheet, containing glass, cotton, and silk; a sulphur aluminum used in cement; a resistant mineral from Sweden; and a coated resistant glass fiber from Johns-Manville.

Someone commented that the materials listed were all fibers used to fortify cement; these products are all cured naturally, therefore, they contain a porcelain cement binder. The products are quite alkaline. The commenter also said that when the matrix in these products is subjected to a temperature in excess of 354 degrees Fahrenheit most of the materials mentioned would dissolve. Also, many of these materials cannot be processed on the same type of machinery that is used to make asbestos products. A fiber will be commercially usable if it can be processed the way A/C pipe is made, if it can be autoclaved and still maintain long term strength and reinforcement to meet all of the American Water Works Association specifications.

Pretention steel pipe up to 54 inches is the most economical pressure pipe. A/C pipe is sold in diameters up to 42 inches.

General agreement was reached that there are substantial competitive products to A/C pipe for all the ranges of pipes. There was also agreement that no fiber is presently available that could substitute directly for asbestos fiber in A/C pipe, as it is presently manufactured and cured in the United States.

Mr. James Warden from the U.S. Engineering and Research Center, U.S. Department of the Interior, commented that most pipe they put in the ground of a size 24 inches and less is A/C pipe regardless of the head. Above 24 inches and up to about 36 inches, the pretention steel pipe is quite competitive, and above that range all the other types of pipe become competitive. A cost-to-performance analysis is important in the selection of a pipe. In a municipality, the operational and maintenance costs, or life cycle costs are important.

Equipment costs for adapting an existing process to a new fiber must be considered.

Installation costs will differ from pipe to pipe. A/C pipe is very rigid in all sizes, facilitating its installation, whereas, ductile pipe is non-rigid and therefore more costly to install in larger sizes.

A/C pipe imports are very low. There is a captive market for certain specifications of pipe.

ENERGY UTILIZATION

Energy is utilized by substitutes in the physical product and in manufacturing. Various associations have calculated their own ratio's of energy utilization, but these calculations may be biased. For example, A/C pipe used 4 times more energy than PVC pipe; 2 times more than concrete pipe; and, 8 times more than cast iron pipe.

RESEARCH AND DEVELOPMENT

Linings and coatings for pipe are being investigated to eliminate the leaching of harmful substances from the pipe itself or the surrounding area into whatever material is conveyed in the pipe. A/C pipe does not corrode externally but might corrode internally in aggressive water. TCE can leach out into water. Sometimes coal-tar pitch, asphalt (petroleum-based) and steel can be used as (external) coatings. A perfect lining has not been found.

PRODUCT SPECIFICATIONS

There are no pipe specifications or generic standards. Pipes are made to meet the criteria of the American Water Works Association (AWWA) or the American Society for Testing and Materials (ASTM).

PRODUCT AND SUBSTITUTE MATERIAL REVIEW SESSION

The purpose of the Product and Substitute Material Review Session was to provide a forum in which any expert on a substitute for asbestos fiber or an asbestos-containing product could present information about the substitute. Those who were interested in participating in this session were sent guidelines informing them what type of information they should supply. The following, are the edited excerpts from information supplied to EPA, organized alphabetically by the name of the organization submitting the information. The data presented are believed to be correct, but EPA cannot guarantee their accuracy. It should also be understood that EPA and CPSC do not endorse any products.

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COMPANY NAME Amatex Corporation
1032 Stanbridge St.
Norristown, Pa. 19401

PRODUCT NAME Nor-Fab and Thermoglass Industrial Textiles

APPLICATIONS

Nor-Fab

- Yarns
- Roving
- Filler
- Tapes
- Cords
- Braided tubing and packing
- Twisted and braided ropes
- Fabric

Thermoglass Textiles

Cloth applications

- Lagging
- Welding shields
- Fire blankets
- Laminating
- Flange and valve covers
- Spray shields
- Stress relieving
- Protection of flexaust hose in steel mills

Tape applications

- Pipe, meter line, and hose wrapping
- Oven door seals
- Fabricating tadpole gasketing
- Thermal insulation
- Pipe hangers

Tubing applications

- Protection of metal tubing, thermocouple leads, hose lines, wire and cable
- Stress relieving
- Oven door seals and thermal insulation

Rope applications

- Packing for furnace doors, boilers
- Core tadpole tape

Suitable for:

- Nor-Fab could replace Commercial Grade and Underwriters' Grade asbestos material (75 to 80 percent asbestos content).
- Thermoglass could replace asbestos products from Commercial Grade through AAA grade (75 to 95 percent asbestos content).

Situations substitute not adequate:

- Nor-Fab not suitable to replace high grades asbestos such as AA and AAA grade materials.
- Thermoglass not suitable for temperatures above 1000°F.

PHYSICAL PROPERTIES/PERFORMANCE/TEST RESULTS

Nor-Fab

TYPICAL PROPERTIES

Color	*Light Yellow*
Fiber Make-up	*Non-asbestos*
Mildew Resistance	*Excellent*
Abrasion Resistance	*Very Good*
Stretch Resistance	*Very Good*
Flexibility	*Very Good*
Workability	*Excellent*
Heat Resistance	*Excellent to 650°F*
Color Change	*Darkens at high temperature*
Weight Loss	*Very slight to 650°F*
Strength Retention	*Excellent to 500°F*

DATA—22PT7 CLOTH—within 10%

Breaking Load (1" ravel)	*Warp—185 lbs.* *Fill—95 lbs.*
Effect of High Temperature	*Does not melt, decomposes between 700°F and 840°F*
Weight Loss	*2% at 660°F*
Strength Retention	*54% at 660°F*
Specific Gravity	*1.51*
Soluble Chlorides	*Less than 100 ppm*
Ph	*7.2*
Corrosion & Chemical Resistance	*In compliance with MIL-I-24244A*
Electrical Resistance ASTM D-257	3.0×10^{10}
Thermal Conductivity *K*—ASTM C-177 "Thermal Conductivity by Guarded Hot Plate Method"	$K = \frac{(Btu - In)}{(Hr \cdot Ft^2 \cdot {}^\circ F)}$ *(Av. Temp 77.73°F)* $K = 0.560$
Total Conductance	$C = 8.08$
Total Resistance *R*	$R = 0.124$

CHEMICAL RESISTANCE—NOR-FAB 22PT7

CHEMICAL	CONCENTRATION (%)	TEMP °F	TEMP °C	TIME HRS	EFFECT ON BREAKING STRENGTH: None Less than 10%	Slight 11-25% loss	Moderate 26-50% loss	Appreciable 51-80% loss	Degraded 81-100% loss
ACIDS									
Hydrochloric	35	70	21	1	x				
Nitric	70	70	21	1				x	
Sulfuric	70	70	21	1	x				
ALKALIS									
Ammonium Hydroxide	57	70	21	1		x			
Sodium Hydroxide	50	70	21	1		x			

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Thermoglass Textiles

NONFLAMMABLE: THERMOGLASS products will not burn or smolder.

HIGH HEAT RESISTANCE: May be used at surface temperatures ranging from 120°F to 1000°F. Retains 50 percent of tensile strength at 700°F, and as much as 25 percent at 1000°F.

EXCELLENT DIMENSIONAL STABILITY: Will not stretch or shrink. No more than 3 percent elongation under maximum stress. Retains stability even at high temperatures.

HIGH TENSILE STRENGTH: Highest strength-to-weight ratio of any industrial textile product.

CHEMICAL RESISTANCE: Inorganic THERMOGLASS is highly resistant to most chemicals. Will not rot or mildew.

EXCELLENT ELECTRICAL PROPERTIES: High dielectric strength and low constants.

GREATER FLEXIBILITY: The very fine filaments used in making THERMOGLASS give it a high degree of flexibility.

FINISHES: THERMOGLASS textiles can be treated with special finishes to meet specific requirements. These finishes include: heat treatment to improve cutting and sewing, waterproof finish, rewet finish, pre-applied adhesive. It can also be supplied with aluminum foil, Neoprene or vinyl finish.

Performance Standards

MEETS U.S. COAST GUARD REQUIREMENTS: THERMOGLASS conforms to U.S. Coast Guard requirements for Incombustible Materials, subpart 164.009.

APPLICABLE SPECIFICATIONS: Amatex THERMOGLASS products can be manufactured to meet U.S. Government specification MIL-C-20079 and other customer specifications, as required. For insulation materials with special corrosion and chloride requirements, THERMOGLASS products can be supplied in conformance to MIL-I-24244.

COSTS IN PRODUCTION

Costs of process changes: No change required by the users to switch from asbestos to a substitute.

Production costs compared: Same as asbestos.

COSTS IN USE

Information not supplied.

In the case of a government restriction on asbestos, increased production is not expected to reduce costs.

LIFETIME COSTS OF USING PRODUCTS

Just about equal.

HEALTH INFORMATION

Thermoglass: To the best of our knowledge no health hazards are known except possible skin and eye irritation.

Nor-Fab 400 Series: Aramid fibers as used for these products are supplied by E. I. DuPont De Nemours & Co. and have been tested by them for toxicity by skin contact tests on animals and humans. No toxic reactions have been observed. No reports of skin irritation or other health hazards associated with this fiber during extensive market development activity.

BIBLIOGRAPHIC INFORMATION

Thermoglass:

Owens Corning Fiberglass
Pittsburgh Plate Glass

Nor-Fab

E. I. DuPont De Nemours
Owens Corning Fiberglass
Pittsburgh Plate Glass

Manufacturer's Contact:

Mr. W. Maaskant
Amatex Corporation
1032 Stanbridge St.
Norristown, Pa. 19401

COMPANY NAME The Andersons
Cob Division
P.O. Box 119
Maumee, OH 43537

PRODUCT NAME Grit-O'Cobs®, Mix-O'Cobs™, Lite-R-Cobs®

APPLICATIONS

Grit-O'Cobs, Mix-O'Cobs and Lite-R-Cobs corncob products could substitute for asbestos, all or in part, in the following applications.

Lost circulation material for oil drilling

Brake shoe component

Asphalt coatings and sealants

Bituminous concrete

Filler for plastics and flooring

Filler in paper products

Component in gasket material

PHYSICAL PROPERTIES/PERFORMANCE/TEST RESULTS

	Property	Grit-O'Cobs	Mix-O'Cobs	Lite-R-Cobs
Elemental Analysis:	Carbon	43.5%	44.2%	44.8%
	Hydrogen	7.9%	7.4%	6.9%
	Nitrogen	0.21%	0.42%	0.62%
	Oxygen	48.4%	47.9%	47.4%
	Phosphorous	0.021%	0.05%	0.07%
	Sulfur	0.013%	0.12%	0.22%
	Potassium	0.93%	0.90%	0.87%
	Sodium	0.14%	0.11%	0.08%
	Magnesium	0.11%	0.10%	0.09%
	Silicon	0.089%	0.090%	0.090%
	Iron	0.013%	0.015%	0.017%
	Calcium	0.011%	0.04%	0.06%
	Aluminum	0.0053%	0.0054%	0.0054%
	Barium	<0.0001%	<0.0001%	<0.0001%
	Chromium	<0.0001%	<0.0001%	<0.0001%
	Copper	<0.0001%	0.0002%	0.0003%
	Lead	<0.0001%	<0.0001%	<0.0001%
	Manganese	<0.0001%	0.0002%	0.0003%
	Nickel	<0.0001%	<0.0001%	<0.0001%
	Vanadium	<0.0001%	<0.0001%	<0.0001%
	Zinc	<0.0001%	0.0001%	0.0002%
	Selenium	<5 ppb	<5 ppb	<5 ppb
	Cobalt	0.00001%	0.00001%	0.00001%

SELECTED PROPERTIES AND DESCRIPTION OF PRODUCTS

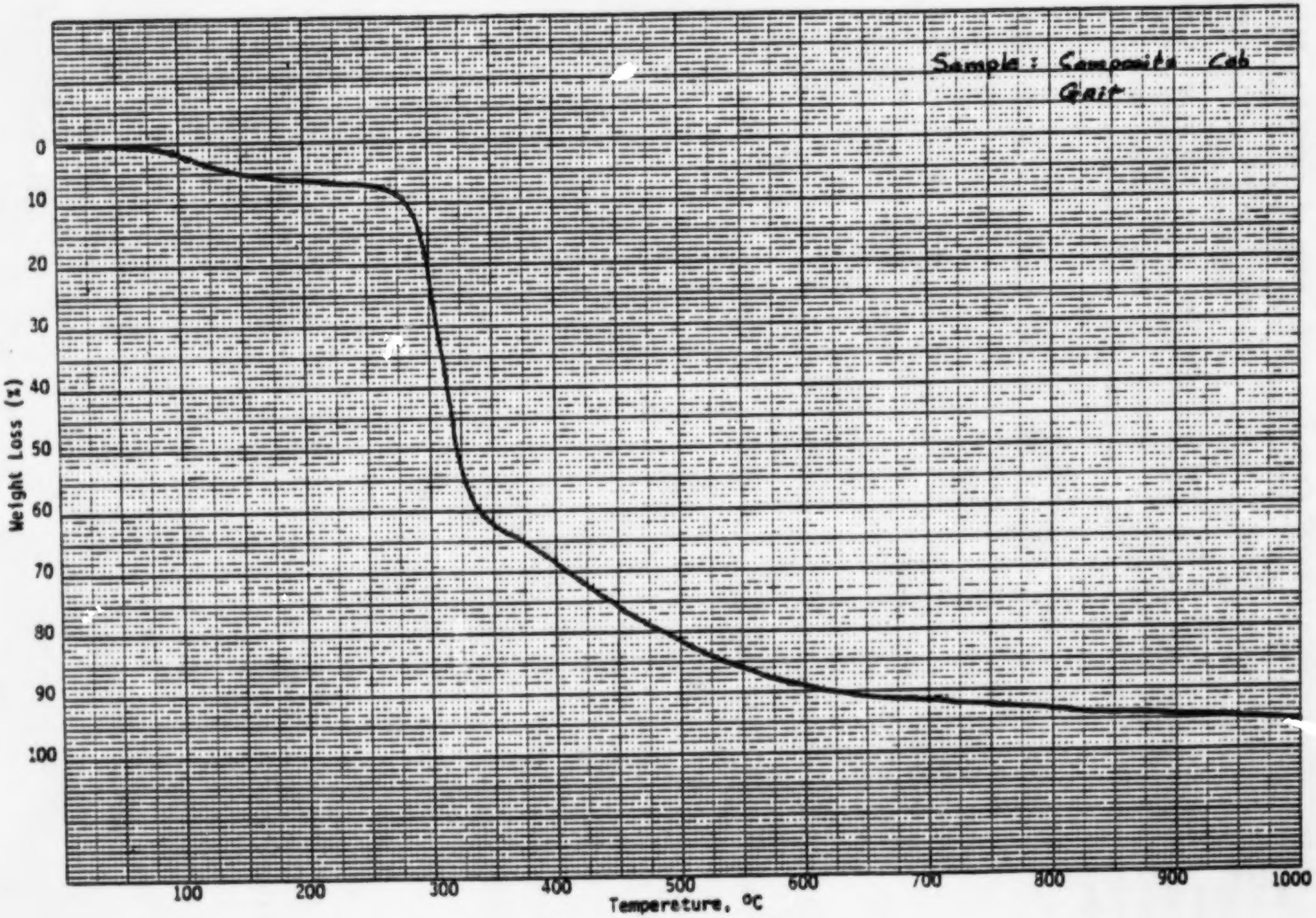
Grit-O'Cobs are manufactured from the woody ring of corncobs, Lite-R-Cobs are manufactured from the coarse chaff, fine chaff and pith of corncobs, and Mix-O'Cobs are produced by blending Grit-O'Cobs and Lite-R-Cobs in a ratio suitable for various end uses. The properties presented herein for Mix-O'Cobs assume a 1:1 blend of Grit-O'Cobs and Lite-R-Cobs. Selected properties of the subject materials are listed below. For additional information on properties, uses and methods utilized to obtain test data, please refer to "Physical Properties, Chemical Properties and Uses of the Andersons' Corncob Products."

Property	Grit-O'Cobs	Mix-O'Cobs	Lite-R-Cobs
Oil Absorption	100%	300%	500%
Water Absorption	133%	430%	727%
Bulk Density	28 lb/ft^3	20 lb/ft^3	12 lb/ft^3
Specific Gravity	1.3%	1.5%	1.6%
Solubility in Acetone	2.5%	2.3%	2.1%
Solubility in Ethyl Alcohol	5.6%	4.8%	4.0%
Solubility in Alcohol-Benzene	9.5%	8.2%	6.8%
Solubility in Benzene	0.4%	0.4%	0.3%
Solubility in Ether	0.3%	0.9%	1.4%
Solubility in Isopropyl Alcohol	0.42%	0.36%	0.29%
Solubility in 1% Potassium Hydroxide	18.6%	18.6%	18.5%
Solubility in 10% Sulfuric Acid	2.5%	2.5%	2.4%
pH (bulk)	4.9%	4.9%	4.9%
pH (surface)	7.4%	7.4%	7.4%

TGA

The Thermogravimetric analysis of the Grit-O'Cobs is shown on the next page. This should be of assistance in defining the temperature limitations of corncob products.

THERMOGRAVIMETRIC ANALYSIS



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RESEARCH AND DEVELOPMENT

The greatest need for research and development in utilizing corncob products as an asbestos replacement is in the end product use area. This includes the areas of end product formulation and end product performance.

ECONOMIC INFORMATION

Costs in Production:

Where a corncob product can be directly substituted for asbestos, there would be little or no cost associated with process changes. Where a corncob product is substituted in part for asbestos, the economics are more complex because the corncob product is only one of the materials involved in the substitution. The costs associated with the latter substitution would be expected to vary from product to product and from formulation to formulation.

Costs in Use:

The cost of Grit-O'Cobs, Mix-O'Cobs and Lite-R-Cobs products vary from roughly 5 to 10 cents per pound depending on the grade, the quantity purchased and whether it is purchased in bulk or bags.

HEALTH INFORMATION

A product safety and regulatory compliance bulletin is enclosed. This contains health information on corncob products.

BIBLIOGRAPHIC INFORMATION

Pages 357 through 385 of "Physical Properties, Chemical Properties and Uses of the Andersons Corncob Products" give bibliographic information on corncob products. A copy of this publication can be obtained from the manufacturers' contact.

MANUFACTURERS' CONTACT

Dr. Kevin M. Foley should be contacted for technical information on corncob products. David Vander Hooven should be contacted for information on price and availability. The address and phone number of these people is given below.

The Andersons
P.O. Box 119
Maumee, OH 43537
(419) 893-5050

APPENDIX A

PRODUCT SAFETY & REGULATORY COMPLIANCE INFORMATION BULLETIN FOR CORNCOB PRODUCTS

(1) Chemical Composition of Corncob Products

	Corncobs	Grit-O'Cobs® granules	Lite-R-Cobs® granules
Cellulose	41%	47%	35%
Hemicellulose	36	37	37
Pentose fraction	35	37	35
Xylan fraction	30	32	30
Lignin	6	7	5
Moisture	10	7	6
Protein	2.5	1.4	4.4
Fat	0.5	0.2	0.9
Ash	1.5	1.2	1.6

pH (bulk) 5 (determined in 1 to 4 (w/w) ratio of Grit-O'Cobs granules to Water (dist.))

(2) Pesticide Residue Information

A typical analysis of Grit-O'Cobs contained less than 0.02 parts per million of aldrin, gamma-BCH, BHC, chlordane, DDD, DDE, DDT, diazinon, dieldrin, disulfoton, endrin, ethion, heptachlor, heptachlorepoxide, lindane, malathion, methyl parathion, parathion, thimet, thiodan, trithion.

(3) Fire and Explosion Properties

Property		Test Method
Ignition Temperature (Grit-O'Cobs Granules)	401°F	(ASTM D-1929-68)
Fire Point - Open Cup (Grit-O'Cobs Granules)	388°F	(ASTM D-92-66)
- Closed Cup (Grit-O'Cobs Granules)	396°F	(ASTM D-93-71)
Flash Point - Open Cup (Grit-O'Cobs Granules)	350°F	(ASTM D-92-66)
- Closed Cup (Grit-O'Cobs Granules)	388°F	(ASTM D-93-71)
Minimum Explosive Concentration (-200 Mesh Grit-O'Cobs Dust Cloud)	0.045 oz/cu ft	(U.S. Bureau of Mines Report 5624)

COMPANY NAME Carborundum Company
Insulation Division
P.O. Box 808
Niagara Falls, NY 14302

PRODUCT NAME Ceramic Fiber Paper, Board, Cloth, Rope

APPLICATIONS

Cloth

- Furnace curtains
- Expansion joints
- Welding cloth
- Pipe and hose wraps insulation (tape and sleeving)
- Equipment and personnel protection
- Maintenance cloth

Rope

- Door seals - furnace ovens
- Flange and burner gaskets
- Static packings

Paper

- Electric and thermal insulation for transformer coils
- Thermal insulation for oven appliances (self-cleaning)
- Tap out cones for molten aluminum
- Flat gasketing
- Expansion joint material
- Muffler insulation

Fiberboard

- Thermal protection in large circuit breakers
- Fireproofing for commercial and residential security boxes, safes, and files
- Aluminum pouring trough cover and liner

PHYSICAL PROPERTIES/PERFORMANCE/TEST RESULTS

Textiles

Color - White
Composition - Alumina/silica
Continuous use limit - 2300°F
Melting point - 3200°F
Breaking strength (rope) - 80 lbs
Organic content - 20 to 25 percent

Paper

Composition - Alumina/silica
Organic content - 6 to 10 percent
Tensile strength - 120 psi
Burst strength - 4 lbf
Density - 10 to 20 lb/ft^3
Continuous use limit - 1300 to 2600°F
Thermal conductivity - 0.36 at 400°F

Board

Composition - Alumina/silica
Continuous use limit - 2300°F
Tensile strength - 180 psi
Organic content - 6 to 7 percent
Thermal conductivity - 0.53 at 400°F

COSTS IN PRODUCTION

Information not supplied.

COSTS IN USE

Information not supplied.

HEALTH INFORMATION

Not supplied.

BIBLIOGRAPHIC INFORMATION

Not supplied.

MANUFACTURER'S CONTACT

B.J. Glazier or K.C. Pietak
Carborundum Company
Insulation Division
P.O. Box 808
Niagara Falls, NY 14302

COMPANY NAME Celanese Plastics and Specialties Company
26 Main Street
Chatham, NJ 07928
(201) 635-2600

PRODUCT NAME Celiox^{TM} Fibers

Celiox^{TM} fibers are heat stabilized polyacrylonitrile which has been subjected to a treatment that results in cyclization, crosslinking and oxygen addition.

APPLICATIONS

Some applications are:

- Protective garments
- Fire proximity suits
- Heat resistant gloves

PHYSICAL PROPERTIES/PERFORMANCE/TEST RESULTS

Typical Celiox Filament Properties

Density, g/cc	1.4
% Moisture Regain, (65% RH)	10
Electrical Resistivity, Ohm-cm	$>10^{10}$
Tensile Strength	
g/denier	1.7
psi, x 10^3	30.5
Tensile Modulus	
g/denier	90
psi, x 10	1.6
Elongation, %	10
Color	Black

Response of Celiox to Heat

Limiting Oxygen Index	50% O_2 required to sustain ignition
Flammability in Air AATTC Method 5903	Does not ignite No afterglow Zero char length
Melting Point	Converts to carbon Sublimation Point 6600°F (3650°C)

Exposure to Molten Metal*

Aluminum @ 1400°F	Runs off fabric at 70° angle, no burn through
Steel @ 2850°F	Runs off fabric at 70° angle, no burn through
	Horizontal fabric withstands 1 lb. spash without burn through

Other Properties

Celiox fibers may be readily converted into carbon fibers. High temperatures convert Celiox fiber from a heterocyclic polymer to pure carbon. The reaction is rapid at temperatures above 600°F (360°C). Under controlled conditions, the carbon fiber can develop strength and modulus several times that of the starting fiber but at a sacrifice in elongation. Carbon fabrics find uses as reinforcement of ablative and structural composites for high temperature service in aircraft disc brakes and rocket nozzles.

RESEARCH AND DEVELOPMENT

Information not supplied.

COSTS IN PRODUCTION

Information not supplied.

COSTS IN USE

Has processability on conventional textile equipment.

HEALTH INFORMATION

Not supplied.

MANUFACTURER'S CONTACT

Mr. W.D. Timmons
Celanese Plastics and Specialties Company
26 Main Street
Chatham, N.J. 07928

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* Gentex Dual-Mirror™ aluminized fabric, 13 oz/yd^2 Celiox fiber.
Gentex Corp., Carbondale, Pa.

COMPANY NAME E. I. DuPont de Nemours and Company, Inc.
Wilmington, DE 19898

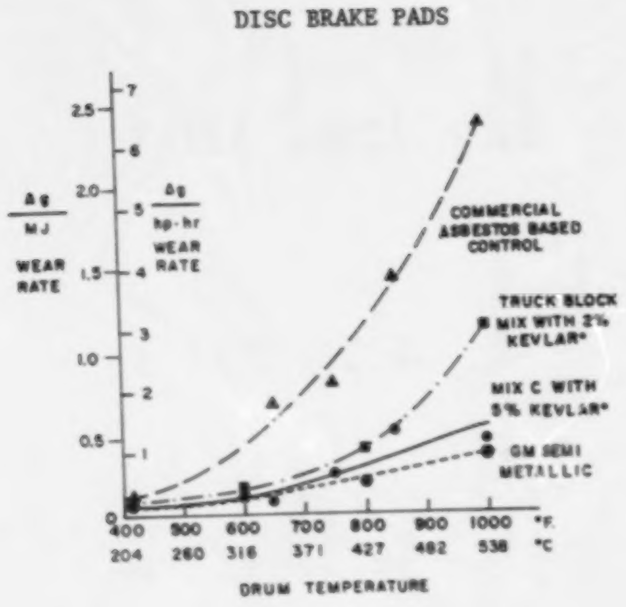
PRODUCT NAMES Kevlar® and Nomex® Aramid Fibers

PHYSICAL PROPERTIES/PERFORMANCE/TEST RESULTS

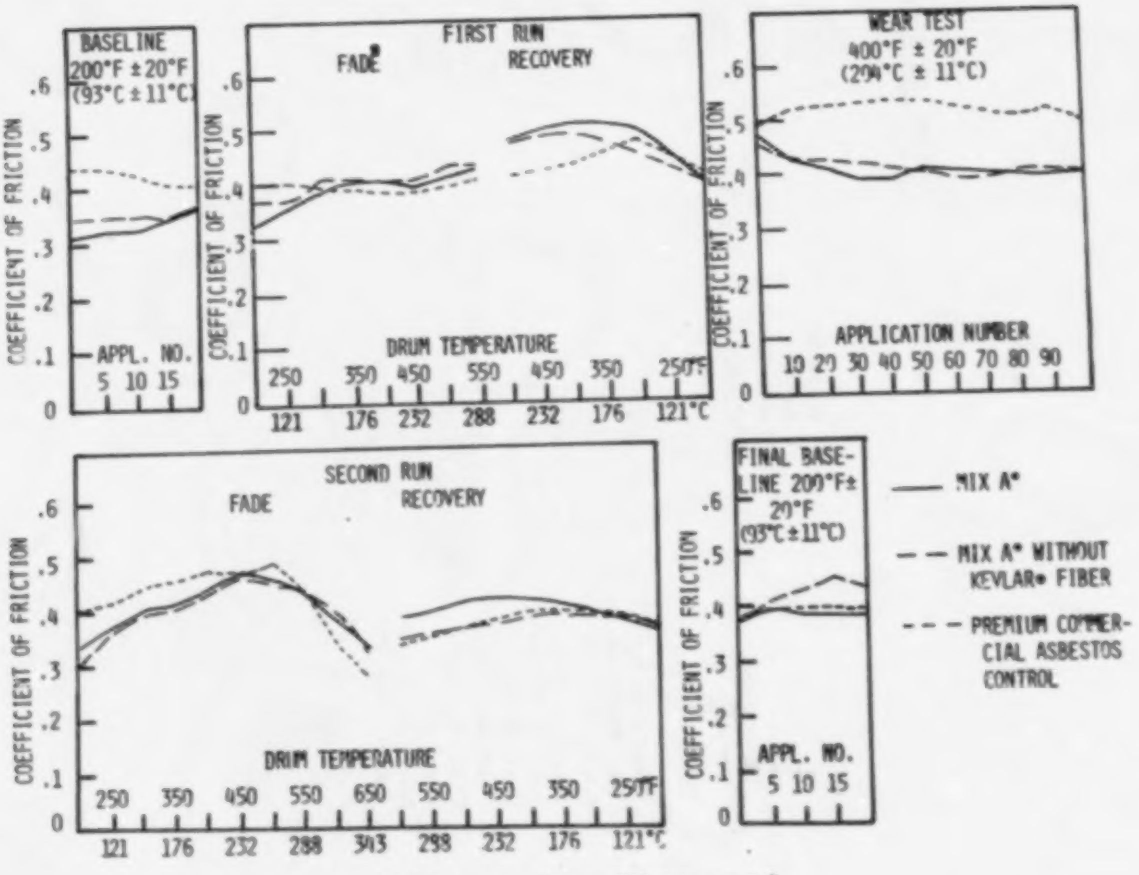
FIBER/FORM:	KEVLAR®			NOMEX®	
PHYSICAL PROPERTIES	FILAMENT	STAPLE YARN	CHOPPED, PULP	FILAMENT	STAPLE YARN
Density, gm/cc	1.45	1.45	1.45	1.38	1.38
Denier/Filament	1.5	1.5	1.5	1.5	1.5
Filament Dia., mils	.47	.47	≤.47	.50	.50
Filament Length, Ins.	Cont.	1.5-4.0	.08-.25	Cont.	1.5-3.0
Tenacity, gm/denier	22	9-13	≤22	5.3	3.5-4.5
Tensile Strength, psi x 10^{-3}	400	160-230	≤400	100	65-80
Modulus, psi x 10^{-6}	10	10	10	2.5	1.3-2.2
Elongation, %	4	5	4	22	35-22

THERMAL PROPERTIES

	KEVLAR®	NOMEX®
Shrinkage % at		
177°C. (350°F)	0	<1.0
285°C. (545°F)	0.5	2.5
In flames (815°C. or 1500°F)	0.5	>40
Max. Continuous use Temp. °C	150-205	205-260
°F	300-400	400-500
Decomposition Temp. °C.	~480	~425
°F	~900	~800
Limiting Oxygen Index (LOI)	29	29



High temperature wear



J661A test plots (Chase test)

KEVLAR® ARAMID FIBER

APPLICATION:	Thermal Fabrics (Gloves & Curtains)	Clutch Facings	Brake Pads	Friction Papers	Gaskets (Beater - Add & Compressed)	Plastics Reinfmt.
PERFORMANCE						
Fiber Content, %	100	20-30	2-5	5-15	3-6	2-50
Specific Gravity	1.45	1.6-2.2	1.6-2.2	1.6-2.2	1.5-2.0	1.3
Coef. of Friction	N/A	.2 - .6	.2 - .6	--	N/A	N/A
Friction Fade	N/A	Stable	Stable	Stable	N/A	N/A
Wear Resistance	Excellent	Excellent	Excellent	Excellent	--	Excellent
Wear on Mating Surface	N/A	low	low	low	low	low
Thermal Conductivity	low	low	low	low	N/A	N/A
Creep	N/A	low	low	low	low	low
Coef. of Thermal Expansion	N/A	low	low	low	low	low

NOMEX® ARAMID

APPLICATION:	Thermal Insulation	Protective Clothing	Electrical Insulation
Product Form:	Fiber	Fiber	Fiber
PERFORMANCE			
Specific Gravity	1.38	1.38	.3-1.38
Coef. of Thermal Expansion	low	Low	Low
Thermal Conductivity, BTU. in/hr. ft. ^{2} °F	.24	.24	.3 - .8
Dielectric Strength, Volts/mil	N/A	N/A	850
Resistance to Acid	Good	Good	Good
Resistance to Caustic	Good	Good	Good
Resistance to Solvent	Excellent	Excellent	Excellent
Limiting Oxygen Index	29	29	24-32

COST IN PRODUCTION

Information not supplied.

COST IN USE

KEVLAR® ARAMID FIBER (1980 prices)

APPLICATION:	Thermal Fabrics (Gloves & Curtains)	Clutch Facings	Brake Pads	Friction Papers	Gaskets (Beater - Add & Compressed)	Plastics Reinfmt.
Fiber Price, $/lb.	5.75	5.50	3.75-5.00	3.75	3.75	3.75-5.75
Lifetime Cost, Asbestos = 1.00	1.00	.60-1.00	.60-1.00	1.00	1.05-1.50	1.00-1.10

NOMEX® ARAMID

APPLICATION:	Thermal Insulation	Protective Clothing	Electrical Insulation
Product Form:	Fiber	Fiber	Fiber
Price, $/lb.	6.10-19.00	6.10-19.00	6.43-14.26
Lifetime Cost, Asbestos = 1.00	.90 - 1.20	1.30 - 1.50	1.50-3.00

HEALTH INFORMATION

KEVLAR® Aramid Fiber Material Safety Information

Kevlar® aramid is an aromatic, organic composition of carbon, hydrogen, oxygen and nitrogen. When burned, its combustion products are similar to those of other organic materials comprised of the same four elements; their exact composition depends on the conditions of combustion (temperature, availability of oxygen, etc.). Kevlar® yarn is not readily biodegradable and contains no significant percentage of material extractable in water so its effect on ground water in case of landfill disposal should be negligible.

Kevlar® yarns as supplied by Du Pont have been tested for toxicity by skin contact tests on animals and humans. No toxic reactions have been observed. We have received no reports of skin irritation or other health hazard associated with this fiber during six years of extensive market development activity involving millions of pounds of fiber used in a variety of applications.

Kevlar® is not radioactive, is stable in all recommended use environments and requires no special spill procedures. In handling yarns of Kevlar®, operators should be cautioned of the unusually high strength of this product and the resultant possibility of cuts to hands or fingers caught in loops and tangles.

NOMEX® Aramid Fiber Material Safety Information

Nomex® aramid is an aromatic organic composition of carbon, hydrogen, oxygen, and nitrogen. Nomex® is difficult to ignite and will usually self extinguish in the absence of an external heat source. However, when burned, its combustion products are similar to those of other organic materials comprised of the same four elements; their exact composition depends on the conditions of combustion (temperature, availability of oxygen, etc.). Nomex® is not readily biodegradable and contains no significant percentage of materials extractable in water so its effect on ground water in case of landfill disposal should be negligible.

Nomex® fiber supplied by Du Pont has been tested for toxicity by skin contact tests on animals and humans and by inhalation and feeding tests on animals. No toxic reactions have been observed.

Nomex® fiber is not radioactive, is stable in all recommended use environments, and requires no special spill handling procedures.

BIBLIOGRAPHIC INFORMATION

Not supplied.

MANUFACTURER'S CONTACT

For Kevlar® Aramid Fibers

John C. Norman
Textile Fibers Department
Centre Road Building
Wilmington, DE 19898
Phone: (302)999-3546

For Nomex® Aramid Fiber

Isaac L. Gadsden
Textile Fibers Department
Centre Road Building
Wilmington, DE 19898
Phone: (302)999-3951

COMPANY NAME Evans Products Company
Forest Fiber Products Group
Glass Fiber Division
1115 S.E. Crystal Lake Drive
Corvallis, OR 97330
(503) 753-1211

PRODUCT NAME EVANITE Glass Fiber

EVANITE Glass Fiber is produced in bulk form for the manufacture on 100 percent glass paper and as a furnish additive for cellulose and synthetic media. EVANITE fibers are produced by a rotary flame attenuation method as discrete filaments of varying length. The fibers are available in 12 grades ranging from 0.30 to 9.00 microns in diameter. EVANITE fiber is free of binder and surface sizing additives. Water content is negligible.

APPLICATIONS

EVANITE has been used since 1976 for the manufacture of 100 percent glass fiber paper and as a cellulosic furnish additive to enhance sheet characteristics. Due to the wide range of fiber grades available, EVANITE may be used for such applications as:

- High Efficiency Filtration Media (HEPA)
- Medium Efficiency Filtration Media
- Industrial and Surgical Respirator Media
- Battery Separators
- Cryogenic Insulation
- High Efficiency Thermal and Acoustical Insulation
- Corrosion Resistant Media
- High Temperature Media

The coarser grades of EVANITE may be used as a partial replacement for chopped strand in many applications.

Furnish Additives

EVANITE may be used as an additive to standard cellulosic furnishes to improve or modify various sheet characteristics, including:

- Porosity
- Tear Resistance
- Machine Shrinkage
- Wet Tensile Strength

- Pulp Drainage Rate
- Dimensional Stability
- Drying Rate
- Bulk

PHYSICAL PROPERTIES/PERFORMANCE/TEST RESULTS

Glass Fiber Grades

EVANITE Glass Fiber is available in the following standard grades:

Grade	Reference	Average fiber diameter* (microns)
0250		0.30
0500	AAAA	0.45
1000		0.60
1500	AAA	0.75
2000	AA	0.90
2500		1.60
3000	A	2.70
4000	B	3.20
5000	C	4.50
6000	D	5.70
7000	E	7.20
9000	G	9.00

GLASS COMPOSITIONS

The fiber grades are produced from two borosilicate glass compositions distinguished primarily by their ability to withstand acid attack:

- B Glass--Standard borosilicate. Normally specified for Grades 0250-2500.
- C-Glass--A special, acid resistant composition normally specified for Grades 3000-9000.

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*Based on typical average values as determined by EP tests 02-006 and 02-003 calibrated by actual SEM observation.

PROPERTIES

	B-Glass	C-Glass
Specify Gravity	2.55	2.50
Service Temperature (Estimated)	545°C	565°C
Softening Point*	703°C	735°C

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*ASTM C 338.

CHEMICAL DURABILITY

The EVANITE C-glass composition was developed specifically to withstand extremely harsh acid environments. Both glass compositions perform relatively well in mild alkaline conditions. Performance data, as determined by EP Method 03-002*, are:

Glass	Acid	Alkaline	
B	10.0	8.0	Maximum %
C	2.0	11.0	Weight Loss

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*72 hour Immersion at 77°C

Acid-1.28 s.g. H_2SO_4

Alkaline-ph 10 NaOH

Weight loss associated with immersion in excess of 72 hours is negligible.

SERVICE TEMPERATURE

Depending on the level of product shrinkage tolerable, EVANITE may be used at elevated temperatures in excess of 500°C. EVANITE has also been successfully tested at cryogenic temperatures.

PAPER MAKING CHARACTERISTICS

The EVANITE fiber grades have been developed for use on conventional paper making equipment with only minor adjustments necessary to deal with differences in drainage rates, drying time, and shrinkage characteristics.

DISPERSION

EVANITE disperses exceptionally fast and with a minimum energy input. Every attempt should be made to agitate with care. Beater speed and time should be set at the lowest levels necessary to produce a homogeneous slurry. In this manner, fiber damage will be minimized and the resulting sheet characteristics improved.

EVANITE disperses optimally at a water temperature range of 28 to 32°C and pH 2.8 to 3.5. However, the fiber can be easily dispersed at near-neutral pH.

CONSISTENCY

Fiber concentration should be maintained at minimal levels to reduce fiber damage caused by abrasion during beating. Consistency levels of approximately 0.75 to 1.00 percent in the mixer and 0.05 to 0.10 percent at the headbox are desirable.

COSTS IN PRODUCTION

Information not supplied.

COSTS IN USE

Cost of EVANITE glass fiber as of May 15, 1980.

Grade	Price/lb	Grade	Price/lb
0250	$7.79	3000	$1.14
0500	6.23	4000	0.93
1000	3.26	5000	0.67
1500	2.34	6000	0.66
2000	2.18	7000	0.65
2500	2.00	9000	0.63

HEALTH INFORMATION

Not supplied.

BIBLIOGRAPHIC INFORMATION

Not supplied.

MANUFACTURER'S CONTACT

Alan J. Gnann
Evans Products Company
Forest Fiber Products Group
Glass Fiber Division
115 S.E. Crystal Lake Drive
Corvallis, OR 97330

COMPANY NAME GRC Products, Inc.
17051 IH 35 North
Drawer J
Schertz, Texas 78154
(512) 651-6773

PRODUCT NAME GRC Flat Sheet

GRC is an asbestos-free Glassfiber Reinforced Cement product made by reinforcing a mixture of ordinary Portland cement and a fine aggregate, with alkali-resistant glass fiber. The glass fiber used for the reinforcement of the cement matrix was developed by the British Research Establishment and Pilkington Brothers, Limited of St. Helens, Merseyside, England, to resist the alkali produced during the normal setting and hydration processes in Portland cement.

APPLICATIONS

A few of the many applications of GRC are:

- Carrier board for laboratory tunnel tests
- Electric closet linings
- Fire resistant linings
- Industrial wall partitions
- Fume hood liners
- Lost form work
- Tunnel linings
- Commercial and industrial use as spandrels, soffits, fascia panels
- Commercial and industrial sandwich panel wall systems
- Pizza oven liners and shelves
- Highway noise control/noise barrier
- Rooftop walkways
- Livestock products
  - Feed troughs
  - Sheep dips
  - Pig slurry channels
  - Insulated pig pen slabs

GRC has satisfactory performance at high temperatures for short periods of time. The maximum service temperature of GRC is in excess [redacted]

PHYSICAL PROPERTIES/PERFORMANCE/TEST RESULTS

GRC has properties similar to those of asbestos-cement with one notable exception; impact strength, in which GRC is approximately 10 times stronger than asbestos cement. All current GRC formulations will satisfy ASTM 136 as regards noncombustibility and will be rated 0 on all characteristics measured by ASTM E84.

The results of tests performed on GRC by an independent outside testing laboratory are listed below:

Dimensions of test coupon - 1/4" x 2 1/4" x 14"

Dry Density, PCF - 124.2

Normal moisture content (% of dry weight) - 2.3

Water absorption (% of dry weight) - 4.9

Modulus of elasticity, PSI - 2.4×10^6

Transverse strength, PSI (MOR) - 3300

Compressive strength, PSI - 18,000

Tensile strength, PSI - 2200

Shear strength, PSI - 5300

Brinnel hardness - No. 29

Dimensional change due to moisture (in./in.)

Shrinkage - normal to dry - 0.0014

Expansion - normal to 90% RLF - 0.0004

Expansion - dry to saturated - 0.0015

Thermal expansion (in./in./°F) - 1.3×10^{-6}

Maximum service temperature in excess of 600°F.

All tests and calculations were performed in accordance with ASTM standards C-220, C-459, and C-580.

PERFORMANCE STANDARDS

At this point of time, there are no government or industrial performance standards to be met by the GRC product.

RESEARCH AND DEVELOPMENT

Although GRC is being evaluated as a substitute product in many areas, the basic material (glass fiber reinforced cement) is backed by over 12 years of service and laboratory testing; consequently, GRC is considered a developed material.

COSTS IN PRODUCTION

GRC sheet can be cut and machined with tools suitable for masonry and asbestos cement use. Fabrication of GRC should not require retooling or supplying of new equipment.

Except for the actual price differential between GRC and Asbestos Cement, there should be no change in production costs of using GRC over asbestos cement.

COSTS IN USE

A full range of GRC flat sheet is commercially available. Standard thicknesses of 1/8, 1/4 and 3/8 inch are available from inventory in 4 foot by 8 foot sheets and 4 foot by 10 foot sheets.

GRC sheets are priced on a per square foot basis. Our current quan prices are as follows:

- 1/8 inch - \$0.60 ft^2
- 1/4 inch - \$0.80 ft^2
- 3/8 inch - \$1.05 ft^2

(These prices subject to change without notice.)

There is no question that with further restrictions or a total restriction of the use of asbestos cement sheets resulting in an increased production of GRC, the price of GRC could decrease by as much as 15 to 20 percent.

GRC, having the same excellent general properties as asbestos cement sheet, such as good mechanical strength and chemical resistance, rot proof, fire resistance, heat resistance, and good machining qualities, should perform comparably to asbestos cement sheets with essentially no increase in cost of installation, maintenance and replacement.

HEALTH INFORMATION

The reinforcing material of GRC, Cem-Fil AR glass fibers, do not present any known health hazard during manufacture, installation, on-site working or long term weathering.

BIBLIOGRAPHIC INFORMATION

Additional commercial and technical information on GRC can be obtained from the following sources:

Pilkington Brothers, Ltd.
Cem-Fil Marketing
St. Helens, Merseyside, England

Cem-Fil Corporation
120 Spence Lane
Nashville, Tenn 37211

MANUFACTURER'S CONTACT

GRC Products, Inc.
17051 IH 35 North
Schertz, Texas 78154

Mr. Frank W. Fekete
Mr. Bill Lewis

COMPANY NAME Hill Brothers Chemical Company
One City Blvd. West, Suite 1521
Orange, California 92668

PRODUCT NAME HiFibe

APPLICATIONS (for HiFibe in general)

- Caulks Sealants
- Gasket Forming Compounds
- Cements
- Filler in Plastics
- Swimming Pool Plaster
- Interior and Exterior Plaster and Stucco
- Polyester Resin Filler
- Putty
- Glazing Compounds (Window)
- Crack Filler
- Asphalt Coatings and Cements
- Textured Paints
- Underbody Spraying Mastic
- Mastic
- Block Fillers
- Joint Cements
- Paints
- Vinyl Moulding Compounds
- Taxidermy
- Fiberglass Boats

PRODUCT NAME HiFibe 250, 270, 290

Description

HiFibe 250, 270 and 290 are high fiber content fillers. The fiber in these fillers is HiFibe 2000 which has been dispersed in an inert filler. The method of dispersion insures a very uniform product which does not separate upon mixing. These fillers work well in either water or oil-based systems and show very low shrinkage upon drying.

APPLICATIONS (for HiFibe 250, 270, 290)

As a fibrous filler in cements, caulks, puttys, taping muds, and polyester resins. In asphalt coatings, textured paints, mastics, glazing compounds, and anywhere a high fiber content filler is needed.

RESEARCH AND DEVELOPMENT

We have a staff of chemists working on new formulations and uses of HiFibe.

PHYSICAL PROPERTIES/PERFORMANCE/TEST RESULTS

Specifications

	250	270	290
Bulk density (lb/cu. ft)	39	39	37
Oil absorption	88	106	110
Water absorption	84	100	112
Burn rate	Fiber chars, will not sustain flame		
Moisture content	<1%	<1%	<1%
Color	White	White	White
% fiber	5%	7%	9%
% inert fillers	~95%	~93%	~91%

Limitations

HiFibe should not be used where temperatures exceed 115°C.

Physical Properties

The fiber content of HiFibe varies from 1 percent to 100 percent by weight.

Another major component of HiFibe is C. P. California talc from Pfizer Minerals. The grades of fibers used in HiFibe have average lengths from 0.7 mm to 2.5 mm with an aspect ratio of about 20. These fibers have average coarseness values between 7 and 15 decigrix (1 decigrix = 1 mg/100 mg). This is equivalent to 0.6 to ¼ denier. The branched or fibrillated nature of the fiber results in a very soft flexible fiber.

HiFibe is not designed to resist abrasion, acid and base corrosion or as a noise and thermal insulation.

COSTS IN PRODUCTION

There should be no additional costs for retooling, equipment changes, etc., as no process change would be anticipated.

COSTS IN USE

Depending upon the application, HiFibe will cost about the same as, to twice the cost of using asbestos. Depending primarily upon the percent of synthetic fiber in the HiFibe, the cost of the product at our Los Angeles plant would be 12¢ to $2.00 per pound.

If the government chose to restrict the use of asbestos, this would not change the price appreciably.

If used as recommended, the product produced with HiFibe should have a lifetime cost the same as asbestos.

HEALTH INFORMATION

It is Hill Brothers Chemical's belief that all inhaled dust can be harmful, therefore, we recommend that a dust respirator be worn when handling HiFibe to avoid inhalation of the dust.

BIBLIOGRAPHIC INFORMATION

The fiber used in HiFibe is high density polyethylene. A booklet titled "Fybrel Synthetic Fiber" published by Crown Zellerbach, Chemical Products Division, Vancouver (Orchards) Washington, 98662, describes a HiDensity Polyethylene Fiber in detail.

MANUFACTURER'S CONTACT

Contact Mr. Dean Hill, International Headquarters, Hill Brothers Chemical Company, One City Boulevard West, Suite 1521, Orange, California 92668, phone, Area Code 714, 634-3322.

COMPANY NAME HITCO Materials Group
1600 W. 135th Street
Gardena, CA 90249

PRODUCT NAMES Refrasil (silica textile products)
Carbon and graphite continuous filament yarns

REFRASIL/TECHNICAL CHARACTERISTICS

Applications

- Weld Protection
- Furnace Curtains
- Personnel Shields
- Separator Cloth
- Expansion Joints
- Thermocouple Insulation
- High Temperature Seals/Gaskets
- Hose and Cable Insulation
- Furnace Linings
- Reformer Insulation Containments

Generally speaking, Refrasil can be substituted for asbestos in the same textile product form and provide increased insulation and thermal stability in higher temperatures. Standard Refrasil products can withstand temperatures to 1800°F, whereas asbestos Commercial and Underwriters Grades are only rated at 450°F.

Refrasil is not recommended for safety clothing or protective garments where seam strength and flexing are critical to the integrity of the garment and safety of the wearer. The low break strength and abrasion resistance of Refrasil cloth restricts the application in safety garments to accessories, such as aprons, gauntlets, leggings, etc., where seam strength and abrasion are not critical to the performance of the article.

PHYSICAL PROPERTIES AND PERFORMANCE CHARACTERISTICS

- Chemical analysis - 96 percent minimum SiO_2, traces of metallic oxides.

- Temperature limit - 1800°F before embrittlement occurs.

- Thermal Conductivity - 0.6 $Btu/hr/ft^2/in./°F$ at 400°F to 1.5 $Btu/hr/ft^2/in./°F$ at 1800°F.

- Specific Heat - 0.28 Btu/lb/°F average
- Linear Shrinkage - 2 percent to 12 percent depending upon peak temperature ranges from 800°F to 1800°F.
- Chemical Resistivity - relatively inert to most chemical environments, including acids, except flourine gases and some molten metals such as magnesium, sodium and silicon.
- Permeability (UC 100-96 cloth) - 5.3 cu ft/min/sq ft.
- Abrasion Resistance (UC 100-96 cloth) - 229 cycles.
- Dielectric Strength - 40 volts/mil
- FTM Std. 191, Method 5304 Wyzenbeck Unit, 2 lb load, 2 lb tension, 600 grit paper.

For complete properties and performance characteristics of Refrasil, refer to "Technical Data Bulletin - Engineering Data LHT/MD-3979R."

PERFORMANCE STANDARDS

- MIL-I-24244 Chloride Acceptability
- 40 CFR 164.009 Incombustible Materials
- NNSY 383/IM Refractory Cloth, 2000°F intermittent service, nonasbestos (Norfolk NSY).

RESEARCH AND DEVELOPMENT

The areas in need of improvement in the silica textile products include abrasion resistance and break strength. The material provides thermal performance to 1,800°F and beyond (with special treatments), but fails to provide the durability to withstand the normal industrial environments. Various surface coatings and impregnations have been applied in an effort to improve abrasion resistance and lubricate the individual fibers to reduce failure from flexing.

REFRASIL/ECONOMIC INFORMATION

Costs in Production

In most instances, there is no need for process changes when substituting Refrasil for asbestos textiles in the same form (cloth, tape, sleeving, etc.). The elimination of costs for asbestos compliance usually result in a reduction of overall costs, in spite of the higher (two to three times) initial cost of material for Refrasil over asbestos products.

Costs in Use

The average selling prices of Refrasil in the various product forms available are:

Cloths - $14 to $28/lineal yard

Tapes - $0.40 to $1.60/lineal foot

Sleevings - $2.25 to $5.50/lineal foot

Yarns and Cordages - $26 to $36/pound

Fiber - $10/pound

Batt - $3.75 to $4.50/square foot

Rope - $0.25 to $5.00/lineal foot

Prices vary within product forms due to variables of thicknesses, sizes, and quantities purchased.

Costs of producing Refrasil are directly related to the costs of raw material (leachable glass fiber textile products) and labor. Current pricing policies of the weaver and glass fiber producers do not indicate any cost reductions from increased production volumes.

REFRASIL HEALTH INFORMATION

Due to the size of Refrasil fibers (8 microns in diameter) the possibility of inhaling fibers into the lower respiratory tract is minimized. Therefore, it is believed that with reasonable precautions applied to the handling and use of Refrasil, no health hazard or concern for safety exists. Reference "Technical Data Bulletin - Safety and Health Considerations" LHT/MD-3879 for complete data.

CARBON AND GRAPHITE CORDAGE/TECHNICAL CHARACTERISTICS

Applications

Compression packings (braided)

High Temperature door seals

Vacuum furnace lining thread

The primary use for carbon and graphite filament yarns is in the production of braided mechanical packings for service temperatures above 550°F and highly corrosive environments. Due to the presence of TFE and other organics that serve as lubricants for braiding, these products are not recommended for applications where high-purity and nonhalogens are a requisite (such as nuclear applications).

PHYSICAL PROPERTIES AND PERFORMANCE CHARACTERISTICS

	Carbon	Graphite
Carbon assay (wt %)	92	99
Ash Content (wt %)	0.5	0.5
Breaking strength (lb)	15 (10 ply)	30 (20 ply)
Diameter (in.)	0.05 (10 ply)	0.08 (20 ply)
Yield (yd/lb)	700 (10 ply)	350 (20 ply)
Modulus (lb/in.^{2} x 10^6)	6	6
Tensile (lb/in.^{2} x 10^3)	120	120
Chloride content	-	Less than 50 ppm

Carbon and graphite cordage resists chemical attack except from highly oxidizing substances.

COSTS IN PRODUCTION

Generally, there are no process or manufacturing changes required for carbon and graphite braiding operations. The packing manufacturers may vary lubricants and other additives as it applies to their specific braiding process or equipment.

COSTS IN USE

The carbon and graphite yarns are expensive, but intended for special high-performance braided packings or seals. The average selling prices are:

- Carbon cordage (10 ply) - $25/lb
- Carbon cordage (20 ply) - $22/lb
- Graphite cordage (10 ply) - $35/lb
- Graphite cordage (20 ply) - $32/lb

The superior thermal performance and chemical resistance of carbon and graphite materials allows substitution for asbestos in more critical valve and pump sealing applications with the assurance of longer more reliable service and less frequent replacements due to thermal or corrosion failures. Overall cost comparisons with asbestos packings may be available from the braided packing manufacturers.

HEALTH INFORMATION

Carbon and graphite cordage materials are electrically conductive and can cause interference to electronic signals and communications. Consequently, precautions against indiscriminate disposal of materials are advisable.

BIBLIOGRAPHIC INFORMATION

For complete properties and performance characteristics of Refrasil, refer to "Technical Data Bulletin-Engineering Data LHT/MD-3979R."

MANUFACTURER'S CONTACT

Robert E. Portik,
HITCO Materials Group
1600 W. 135th Street
Gardena, CA 90249
(213) 321-8080

COMPANY NAME Janos Industrial Insulation Corporation
80 West Commercial Avenue
Moonachie, New Jersey 07074

PRODUCT NAMES Nu Board 1800

This is an asbestos-free board made from mineral fibers and silica.

Thermonol Textiles

These are replacements for commercial grade asbestos cloth, useable for temperatures up to 650°F.

Glastemp Textiles

This line of glass textiles can replace asbestos up to AA grade.

Siltemp Textiles

This is a product line of high-temperature textiles for replacement of AAA grade asbestos. It can be utilized for temperatures up to 3000°F.

Cem-Fil GRC/125

This product is being used as a replacement for asbestos-cement sheets. It is manufactured in the same sizes, and can also be molded to fit various specifications.

Glasspaper

This product is being utilized to replace asbestos paper rolls for the home consumer.

APPLICATIONS

Some typical uses for Nu Board 1800

- Lining furnaces
- Moving picture booths
- Elevator shafts
- Ceilings, walls exposed to heat
- Gaskets
- Stoves
- Electric ovens
- Glass Lehr rolls
- Float glass conveyor rolls
- Cores for metal clad doors
- Stove pads, welding pads
- Incinerators
- Heater lining
- Strongbox lining
- Kiln lining
- Molded for troughs
- Cable protection

Uses for Thermonol Textiles

- protective garments, weld curtains, insulation barriers, insulation pads, sleeving for thermocouples, cable tapes, gaskets for wood-burning stoves.

Uses for Glastemp Textiles

- weld shields, gaskets, stress relieving applications, safety blankets, protection of flexible hose, door seals, tadpole gasketing, packing furnace doors.

Uses for Siltemp Textiles

- same as listed above only for higher temperatures.

Uses for Cem-Fil GRC/125

- mounting of electrical equipment, bakery ovens, casings over boilers, cooling towers, skirting on buildings, machined parts.

Uses for Glasspaper

- wrap paper for fire protection, protection for soldering, welding, lining barbecue pits, wrapping gas tanks for storage, iron rests, muffler wrap.

PHYSICAL PROPERTIES/PERFORMANCE/TEST RESULTS

Physical Properties of Nu Board 1800 (nominal):

- Color - Beige
- Density - 66.8 lb/ft^3
- Tensile strength - 711 $lb/in.^2$
- Flexural strength - 1280 $lb/in.^2$
- Compression at 3000 psi - 30 to 40 percent
- Ignition loss - 20 percent max
- Moisture content - 3 percent
- Thermal conductivity - 0.0636 Btu/hr/ft/°F
- Flammability - Will not burn
- Heat resistance - Up to 1800°F dependent upon application

Dimensions

- Thickness range - inclusive 3/32" to 1/2"
- Sheet size - 40" x 40"

COSTS IN USE

Nu Board 1800

20 to 25 percent higher than the existing asbestos sheets, however, it has a longer life at higher temperatures.

Thermonol Textiles

Approximately 10 to 15 percent above asbestos prices.

Glastemp Textiles

5 to 10 percent higher than asbestos price.

Siltemp Textiles

Approximately 30 to 35 percent higher than asbestos.

Glasspaper

Approximately same as asbestos.

COST IN PRODUCTION

Information not supplied.

HEALTH INFORMATION

Not supplied.

BIBLIOGRAPHIC INFORMATION

Not supplied.

MANUFACTURER'S CONTACT

T.J. Connolly
Janos Industrial Insulation Corporation
80 West Commercial Avenue
Moonachie, New Jersey 07074

COMPANY NAME Manning Paper Company
P.O. Box 328
Troy, New York 12181

PRODUCT NAME Manniglas 1200, 1400, 1270, 1276, and 1277 material

APPLICATION

Application examples:

Manniglas 1200 and 1400 have an Underwriters' Laboratories 94V-0 recognition and are suitable products where this test criteria is important to the end product.

Pneumatic tube bundle heat protection wrap light fixture heat shields when laminated to aluminum foil.

Hand held hair dryers and other appliance heat shields with and without foil lamination.

Components of tape composites for high temperature cable wrap.

Manniglas 1276 for skin applications on:

(a) urethane and isocyanurate

(b) rigid foam boards--vinyl laminations substrate to impart flame barrier

(c) glass bat or compressed mat flameproof surface skin to impart smoother surface

PHYSICAL PROPERTIES/PERFORMANCE/TEST RESULTS

Glass fiber temperature limitations are in the 1300-1500°F range. At these temperatures the product will soften and the glass will melt at 1500°F.

Glass fiber papers are lower in density than asbestos fiber papers and consequently are a much lower actual weight. Usual estimates are one-third the weight range of the asbestos materials and therefore overall coverage costs are usually competitive with current asbestos materials.

PERFORMANCE STANDARDS

Manniglas 1200 and 1400 have an Underwriter's 94V-0 recognition.

RESEARCH AND DEVELOPMENT

Information not supplied.

COSTS IN PRODUCTION

Information not supplied.

COSTS IN USE

Cost varies from 11¢ to 13¢ per square foot, depending on thickness of the material.

HEALTH INFORMATION

Not supplied.

BIBLIOGRAPHIC INFORMATION

Not supplied.

MANUFACTURER'S CONTACT

John M. North
Manning Paper Company
P.O. Box 328
Troy, New York 12181
(518) 273-6320

COMPANY NAME NEWTEX INDUSTRIES, INC.
P.O. Box 25
Victor, New York 14564

PRODUCT NAME ZETEX™

APPLICATIONS

Curtains: welding, fire, drop, oven

Blankets: stress relieving, welding, thermal insulation, safety

Industrial: expansion joints, electrical insulation, piping insulation, gas and liquid filtration, scrubbers, acoustical insulation, reinforcements, laminates, folded and rubberized gaskets.

Safety: garments, gloves, mittens, spats, sleeves, aprons

Engineered Products: door seals, tad-pole gaskets, pads, etc.

Applications in which the product may not work are those in which cut-resistance of the material is required; e.g., gloves and mittens. The products can be reinforced with leather or an additional layer of ZETEX as is commonly done with asbestos.

PHYSICAL PROPERTIES

Content: Silica-based highly textured yarn

Fiber shape and size: Round with 6 to 9 micron filament

Dielectric characteristics: Dielectric constant of 5.9 to 6.4

Strength: 500,000 psi at 72°F

Elongation: Approximately 5% for yarn

Resistance to abrasion: Taber abrasion tester, CS17 Wheels, 1000 Gm/Wheel

ZETEX 1200 - 493 cycles to failure

ZETEX 1200XP - 1812 cycles to failure

Chemical resistance: Unaffected by most acids, alkalies, solvents, dilute sulfuric acid (with exception of hydrofluoric acid and corrosive environments at elevated temperatures).

Thermal insulation: Thermal conductivity is less than one-half that of asbestos. The thermal conductivity or K-value for ZETEX 1200 is 0.3385.

Leachable chlorides: Less than 0.5 parts per million.

PERFORMANCE

Specific gravity: 2.54

Breaking strength of fabric: 350 to 500 lbs/inch

Tensile modulus for fiber: 10.5×10^6

Coefficient of linear expansion: 2.8×10^6

Specific heat for fiber at 72°F: 0.197

RESULTS OF TESTING

Physical testing conducted in accordance with the appropriate ASTM standard.

The leachable chlorides were done according to military standards MIL-I-24244.

PERFORMANCE STANDARDS

Various military and government specifications are written for asbestos.

RESEARCH AND DEVELOPMENT

Is required in the areas of fiber and finishes.

ECONOMIC INFORMATION

a. No process changes required that we know of.

b. Production costs of using ZETEX are almost identical to those of asbestos except in the safety garment field where they may be higher by about 20%.

c. Costs in use: the price of ZETEX fabrics is about $5.00 to $16.00 per sq/yd to distributors and $7.00 to $22.00 per sq/yd to the end user.

d. If the government chose to restrict the use of asbestos the increased production of ZETEX would cause a decrease in prices of ZETEX products by up to 30%.

e. Depending on application and use, the lifetime cost of using ZETEX products can be lower than asbestos. In safety products, such as gloves and mittens, the cost may be 60 - 80% higher than asbestos products.

HEALTH INFORMATION

Transient mechanical irritation

MANUFACTURER'S CONTACT

Mr. David Moore
Newtex Industries, Inc.
P.O. Box 25
Victor, New York 14564
(716) 924-9135

COMPANY NAME Scan-Pac Manufacturing Company
9950 N. Port Washington Rd.
Mequon, Wisconsin 53092

PRODUCT NAME Complete line of nonasbestos friction materials for clutches and brakes of all types.

TECHNICAL CHARACTERISTICS

Applications

Scan-Pac has available and is selling nonasbestos friction materials for a myriad of uses, some of which are:

- Garage door openers
- Lawn mower clutches
- Rider mower brakes and clutches
- Snowmobiles
- Paper machines
- Wire rope machinery
- Fishing reels
- Snowthrowers
- Medical equipment
- Machine tools
- Winches
- Cranes
- Shovels
- Presses
- Trucks
- Fork lifts
- Buses
- Industrial clutches
- Electric motors
- Hoists

Physical Properties

Content: Depends on compound and see Health Information.

Fiber Shape and Size: Chopped glass fibers of approximately 13 microns diameter.

Dielectric Characteristics: Not applicable.

Strength: Excellent, but varies with compound.

Flexibility: Some compounds flexible, some rigid.

Resistance to Abrasion: Excellent.

Resistance to Corrosion: Not applicable.

Noise: Very quiet brake.

Moisture Absorption: Virtually none.

Performance

Specific Gravity: Varies by compound from 1.7 to 2.6.

Tensile Strength: Varies by compound; typical 2400-5000.

Coef. of Friction: Varies by compound from 0.12 to 0.60.

Results of Testing

All products Chase machine tested per SAE J 661 (see reference 1 and 2 under Bibliographic Information for method of testing and test results).

Performance Standards

Five truck block formulas are certified by American Association of Motor Vehicle Administrators.

Research and Development

Most of the research and development has been done. Dry mix and Wet mix materials research started in 1976 and is still continuing. Product line information can be found in references 1 and 2 under Bibliographic Information. Additional R&D on these items requires more equipment such as dynamometers, experimental molds, experimental grinders. R&D to complete the line has been underway for about 1 year. This includes conversion of all asbestos items to nonasbestos shown in reference 3 of the Bibliographic Information.

ECONOMIC INFORMATION

Costs in Production

The costs of nonasbestos process changes to users is basically the cost of new molds. The cost to Scan-Pac is molds, changes in existing equipment and/or new equipment. In both instances cost is dependent upon size of finished parts.

Scan-Pac's production costs are somewhat higher due to nature of components. We estimate 10 to 20 percent.

Costs in Use

Due to the vastly different sizes of finished parts (see Technical Characteristics) and the number of different materials (see Appendix A, B, and C), it is impossible to assign prices per ton, foot, etc.

We estimate that 20 to 35 percent premium over asbestos product is realistic.

It is doubtful that a government ban on asbestos would lower this percentage, as all components of nonasbestos friction materials are normally produced for other applications.

The lifetime cost of using the nonasbestos product should be lower than asbestos, due to elimination of precautions that must be taken when installing or replacing asbestos. In addition, nonasbestos friction provides longer lining life plus less wear on mating parts.

HEALTH INFORMATION

Scan-Pac's nonasbestos compounds do not contain any materials on Toxic Substance Control list. The raw materials are basically the same found in asbestos friction materials, with deletion of asbestos fiber, and addition of chopped strand glass fiber. The size of the glass fiber (13 micron diameter) is such that it cannot be respired into the human lung.

Scan-Pac's nonasbestos line can fulfill many needs that many asbestos compounds cannot, such as:

1. Longer lining life
2. Less wear on mating surfaces
3. Full range of friction characteristics

We do not know of situations where our materials are not adequate.

BIBLIOGRAPHIC INFORMATION

The following references are available from the manufacturer:

1. Scan-Pac Nonasbestos Industrial Friction Materials
2. Scan-Pac Nonasbestos Truck Blocks
3. Scan-Pac Friction Materials

MANUFACTURER'S CONTACT

Paul Vandenberg
Scan-Pac Manufacturing, Inc.
9950 North Port Washington Road
Mequon, Wisconsin 53092

SCOPE OF THE HEALTH WORKSHOP

by

James N. Rowe, Ph.D
U.S. Environmental Protection Agency
Washington, D.C.

It is my privilege to welcome you to the National Workshop on Health Aspects of Asbestos Substitutes, sponsored by the Environmental Protection Agency (EPA) and the Consumer Product Safety Commission (CPSC). It is appropriate that we dedicate this workshop to the memory of the late Dr. Mearl Stanton of the National Cancer Institute. Dr. Stanton's invaluable contributions to our understanding of the mechanisms of fiber carcinogenesis provide a scientific basis for the rational design of safe asbestos-substitute products.

This workshop provides a forum for discussion of the potential hazards of substitutes, study of the relevant issues, and productive communication among the various segments of the scientific community represented here, including industry, academia, public interest groups, and government. Our work here should provide the regulatory agencies with helpful guidance for dealing with the substitutes issues.

Asbestos substitutes raise complex health issues. This complexity has at least four sources: 1) the diversity, and even the definition, of asbestos-substitutes, 2) our incomplete understanding of the toxicology and pharmacokinetics of fiber and non-fiber particulates, 3) the limited development of adequate scientific criteria for determining toxicities due to factors 1 and 2, and 4) the uncertainty involved in the assessment of quantitative risk to humans by extrapolation from toxicological data in other species.

I will briefly comment on each of these factors.

The first health related factor is the diversity and definition of asbestos substitutes.

Asbestos substitutes deal with a wide variety of materials which may be simplistically labeled fibrous and non-fibrous. Within each category, there are natural and synthetic substances, each having different physico-chemical composition, morphological characteristics, and potential for undesirable and possibly toxic contamination. The workshop agenda illustrates this point and suggests that the term "asbestos substitute" is open to a variety of interpretations.

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The second factor is our limited understanding of the toxicology and pharmacokinetics of fiber and non-fiber particulates.

For example, are short, thin durable fibers (<5 μm length) completely non-toxic and only thin durable fibers (>5 μm length) toxic or is there a gradual transition from the ineffective fiber size to a length which possesses maximum fiber toxicity as hypothesized by Pott[1]? The questions concerning the nature of fiber-induced carcinogenicity and fibrosis and the regulatory decisions made on these issues have significant impact on a very large segment of the industrial community including the mineral and chemical industries. Dr. Stanton's observations are critical for proper evaluation of the fibrous substitutes. His work establishes the in situ potential of a variety of chemically dissimilar, durable fibers to produce mesotheliomas in experimental animals. However, the relationship of intrapleurally produced cancers to carcinogenesis produced by inhalation remains to be established. In inhalation of particles the lungs normal physiological barriers are involved as well as the ultimate biodisposition of the fibers. In addition, the role of co-carcinogens in fiber and particulate toxicology remains to be further defined.

The third factor is the need for reasonable scientific criteria for evaluation of asbestos substitutes.

Because of our limited understanding of the mechanisms of fiber and non-fiber induced chronic toxicity, appropriate testing batteries or scientific criteria can, at best, provide only a rough approximation of the hazard. In a 1974 editorial on fiber carcinogenesis[2] Dr. Stanton noted that, "Our present systems of assessing carcinogenicity in animals can at best only detect response to large numbers of fibers; therefore, materials containing only a few exceptionally fine fibers could easily escape detection as a hazard in simply designed animal tests. Even with the most sophisticated test, it would be difficult to establish an absolute threshold of safety, since each small exposure possibly adds to the total hazard and represents a finite, albeit small, ultimate risk." It behooves us to understand the state-of-art for evaluation of substitutes and to develop scientific criteria which most accurately reflect that understanding. This workshop should provide use with information on the health hazards of asbestos substitutes and some thoughts on defining our approach to evaluating substitutes.

Finally we come to the issue of quantitative risk assessment in humans.

The last factor relates to the extrapolation of in vivo and in vitro data to humans in environmental exposure situations, i.e., quantitative risk assessment. Many scientific issues remain to be settled. Evaluation of the risk to humans remains a necessary but oftentimes difficult function for regulatory agencies. However, quantitative risk assessment for a material with abundant human data such as asbestos is much less ambiguous since the extrapolation does not require interspecies comparisons between animals and man. This "luxury" of scientific data will not be available for many substitute materials.

In conclusion, the EPA and CPSC recognize the complexity of the scientific and health issues related to asbestos substitutes. However, we also recognize the definite health hazards which may be posed by significant exposure to asbestos, and the need to reduce such exposure where possible. It is therefore important that the potential health hazards of substitutes and the limitations of testing information be clearly defined. Such understanding will allow the development and application of scientific policy which is both coherent and equitable. Such progress should prevent reoccurrence of the tragic disease manifestations which have occurred and are occurring since the introduction of asbestos into American commerce in the 1890's.

I am very pleased by your willingness to participate in this workshop, and I am confident that our efforts will be productive.

REFERENCES

1. Pott, F. Staub-Reinhalt Luft 38(12):486-490. 1978.

2. Stanton, M. J. Nat. Can. Inst. 59(3):633-634. 1974.

INHALATION, DEPOSITION AND CLEARANCE OF PARTICLES

by

Morton Lippmann, Ph.D.
New York University Institute of Environmental Medicine
New York, NY, 10016

ABSTRACT

Inhaled particles can deposit at airway surfaces all along the respiratory tract. For compact particles with diameters >½ μm and for fibers with diameters ≳0.2 μm the probabilities of deposition at specific sites, within specific anatomic regions, and for the respiratory tract as a whole depends upon their aerodynamic diameters and for fibrous particles, on their lengths as well. The fate of deposited particles, and their abilities to induce or exacerbate toxic effects depends critically upon their deposition sites, their cytotoxicities, their clearance pathways, their storage sites and their chemical and physical properties.

This discussion focuses on those properties of asbestos substitutes which are critical in determining their airborne size distributions, respiratory tract deposition probabilities, deposition patterns within the airways, reactions with epithelial cells and macrophages, and their toxic effects. Knowledge of these factors may permit modifications in production specifications and trade utilization of the products in ways which may minimize the potential for toxic effects in the utilization of asbestos substitutes.

The major component regions of the respiratory tract differ markedly in structure, size, function, and sensitivity or reactivity to deposited particles. Thus, a complete determination of dose from an inhaled aerosol depends on (1) the regional deposition, (2) the retention times at the deposition sites and along the elimination pathways, and (3) the physical, chemical, and biological properties of the particles. Here, we will discuss first the factors that determine the amounts and patterns of particle deposition within the component regions of the respiratory tract and then the pathways and dynamics of particle translocation and elimination. Both discussions will emphasize the normal patterns of behavior and transport applicable to particles that are not acutely toxic, but may produce chronic lung disease after extended periods of inhalation exposure.

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FUNCTIONAL ZONES FOR PARTICLE DEPOSITION

The respiratory tract (Figure 1) can be divided into zones on the basis that insoluble particles that deposit in each zone contact or affect different cell populations and/or have substantially different retention times and clearance pathways. Each zone includes one or more anatomic regions. The clearance kinetics for particles deposited in each zone will be discussed in greater detail under Particle Retention.

Particles deposited in the unciliated anterior portion of the nose remain at the deposition sites for a variable and ususally indeterminate time--that is, until they are removed mechanically by nose wiping or blowing, sneezing, etc. After leaving the nares or nostrils, the inspired air passes through a web of nasal hairs and flows through the narrow passages around the turbinates. It is warmed, and moistened, and is partially depleted of particles with aerodynamic diameters larger than 1 μm by impaction on the nasal hairs, at bends in the air path, and by sedimentation. Particles smaller than 0.1 μm can deposit in this zone by diffusion. The surfaces are covered by mucus. Most of the mucus in this region is propelled toward the pharynx by the beating of the cilia, carrying with it deposited insoluble particles. Soluble particles may be dissolved in the mucus. Some mucus moves toward the anterior nares, carrying inhaled whole or dissolved particles into the zone of intermittent mechanical clearance.

Particles inhaled through the nose and deposited in the nasopharynx, or particles inhaled through the mouth and deposited in the mouth and oropharynx, are swallowed within minutes. They pass through the esophagus in or on the mucus coming up from the trachea.

The tracheobronchial or conductive airways have the appearance of an inverted tree, with the trachea analogous to the trunk and the subdividing bronchi to the limbs. The airway diameter decreases distally, but because of the increasing number of tubes the total cross section for flow increases and the air velocity decreases. In the larger airways, particles too large to follow the bends in the air path are deposited by impaction. At the low velocities in the smaller airways, particles deposit by sedimentation and diffusion. Ciliated and secretory cells are found at all levels. Inert, nonsoluble particles deposited in normal ciliated airways are cleared within 1 day via the larynx on the moving mucus.[1]

The zone beyond the ciliated airways is where gas exchange takes place. The epithelium is very thin, and soluble particles are believed to enter the pulmonary blood within minutes. Insoluble particles deposited in this zone by sedimentation and diffusion are removed very slowly with clearance half-times of days, months, or years. The mechanisms for clearing insoluble particles from the alveolar zone are only partly understood, and their relative importance is a matter of some debate, as discussed under Alveolar Clearance.

FACTORS AFFECTING PARTICLE DEPOSITION

Particles deposit in the various zones or regions of the respiratory tract by a variety of physical mechanisms. Deposition efficiency in each region

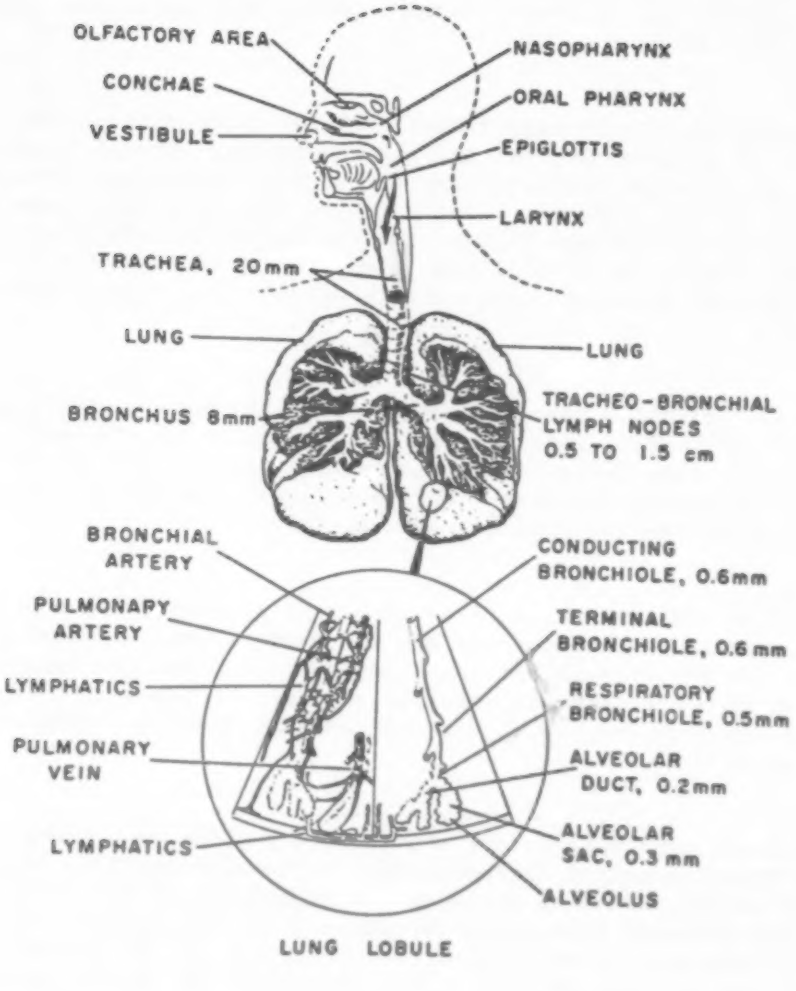
OLFACTORY AREA
CONCHAE
VESTIBULE
NASOPHARYNX
ORAL PHARYNX
EPIGLOTTIS
LARYNX
TRACHEA, 20mm
LUNG
LUNG
BRONCHUS 8mm
TRACHEO-BRONCHIAL LYMPH NODES 0.5 TO 1.5 cm
BRONCHIAL ARTERY
PULMONARY ARTERY
LYMPHATICS
PULMONARY VEIN
LYMPHATICS
CONDUCTING BRONCHIOLE, 0.6mm
TERMINAL BRONCHIOLE, 0.6 mm
RESPIRATORY BRONCHIOLE, 0.5mm
ALVEOLAR DUCT, 0.2mm
ALVEOLAR SAC, 0.3 mm
ALVEOLUS
LUNG LOBULE

Figure 1. Structure of the respiratory tract.

depends on the aerodynamic properties of the particles, the anatomy of the airways, and the geometric and temporal patterns of flow through them.

Deposition Mechanisms

Significant particle deposition can occur within the respiratory tract by five mechanisms: interception, impaction, sedimentation, diffusion, and electrostatic precipitation. However, in most cases, only impaction, sedimentation and diffusion will be important.

Interception--

Interception usually is significant only for fibrous particles. It takes place when the trajectory of a particle brings it close enough to a surface so that an edge contacts the surface; thus the particle size must be a significant fraction of the airway diameter. Fibers 200 μm long have been observed in human lung samples.[2] Straight fibers, such as amphibole asbestos, are more likely to penetrate to the alveoli than similarly sized, but curly, chrysotile asbestos because the straight fibers assume orientations more parallel to the flow streamlines.

Impaction--

Inhaled air follows a tortuous path through the nose or mouth and branching airways in the lung. Each time the air changes direction, the momentum of particles tends to keep them on their preestablished trajectories, which can cause them to impact on airway surfaces. The most likely deposition sites are at or near the carinas of the large airway bifurcations.

Sedimentation--

Gravitational sedimentation is an important mechanism for deposition in the smaller bronchi, the bronchioles and the alveolar spaces where the airways are small and the air velocity is low. Sedimentation becomes less effective than diffusion when the terminal settling velocity of the particles falls below approximately 0.001 cm/sec, which for unit-density spheres is equivalent to a diameter of about 0.5 μm.

Diffusion--

Submicrometer particles in air move randomly under the impact of gas molecules. This Brownian motion increases with decreasing particle size. It becomes an effective mechanism for particle deposition in the lung as the root-mean-square displacement approaches the size of the air spaces. Diffusional deposition is important in small airways and alveoli and at airway bifurcations for particles smaller than about 0.5 μm. For radon and thoron daughters, where the particle size is molecular, diffusional deposition efficiency can be high in the head and in large airways such as the trachea.

Electrostatic Precipitation--

Particles with electric mobility can have enhanced deposition in the respiratory tract even though no external field is applied across the chest. Deposition results from the image charges induced on the surface of the airways by the charged particles. Test aerosols resulting from the evaporation of aqueous droplets can have substantial mobilities, and the results of some experimental deposition studies using such aerosols without charge neutralization are accordingly suspect. Freshly fractured mineral dust particles may also be highly charged.

Aerosol Factors

Particle size is always an important variable in regional deposition. There are a number of ways of expressing particle size. In this discussion, and in most health-related literature, particle size is expressed in terms of actual or equivalent diameters. When particle size is measured by one parameter and expressed in terms of another or equivalent size, the basis for the conversion must be clearly established. Nonspherical particles are frequently characterized in terms of equivalent spheres, for example, on the basis of equal volumes, equal masses, or aerodynamic drag. A parameter in increasingly common use is aerodynamic diameter (D), which incorporates both particle density and drag.

Aerodynamic diameter is the most appropriate parameter in terms of particle deposition by impaction and sedimentation, which usually account for most of the deposition by mass in the head and lungs. On the other hand, diffusional displacement, which is the dominant mechanism for particles smaller than ½ μm, depends only on particle size and not on density or shape. Interception also depends on the linear dimensions of the particle, as well as its shape, since aerodynamic drag can affect the particle's orientation within the airway.

Respiratory and Flow Factors

An important respiratory factor already discussed as a parameter affecting deposition is air velocity. Increasing velocity increases impaction deposition, but decreases sedimentation and diffusion by decreasing residence time. The flow is cyclical and reverses many times per minute. At its peak, flow may be turbulent in the trachea, but the Reynolds number decreases with increasing lung depth, so that in the smaller conducting airways flow is always laminar, and in the alveolar region it is always viscous.[3]

Since flow is laminar in most of the anatomical dead space, the core velocity is almost twice the average velocity. Thus, even in very shallow breathing, a substantial fraction of the inhaled air penetrates beyond the anatomical dead space, and particles with appreciable sedimentation rates (e.g., particles larger than 2 μm) or large diffusional displacements (e.g., particles smaller than 0.1 μm) can deposit efficiently in peripheral airways.

The tidal volume is an important respiratory parameter. The air inhaled at the start of each breath goes deeper into the lung and remains there longer than the air inhaled later in the breath. The deeper the air goes and the longer it stays, the greater the depletion of inhaled particles. Thus, for quiescent breathing--where the air velocity is low, mixing is minimal, and the tidal volume is only two to three times the dead-space volume--a large proportion of the inhaled particles can be exhaled. Conversely, for heavy exertion, where larger volumes are inhaled at higher velocities, both impaction in the large airways and sedimentation and diffusion in the smaller airways and alveoli will be greater.

Anatomical Factors

Intrasubject variations in airway anatomy affect particle deposition in several ways: (1) the diameter of the airway influences the displacement required by the particle before it contacts the airway surface; (2) the cross section of the airway determines the flow velocity for a given volumetric flow rate; and (3) variations in diameter and branching patterns along the bronchial tree affect the mixing characteristics between the tidal and reserve air in the lungs. For particles with aerodynamic diameters below 2 μm, such convective mixing can be the single most important determinant of deposition efficiency.

There are also significant intersubject differences in respiratory tract anatomy. For example, the average alveolar-zone airspace dimension has a substantial coefficient of variation when measured either post-mortem on lung sections or in vivo by aerosol persistence during breath holding. In the former case, Matsuba and Thurlbeck[4] reported a mean size and variation of 0.678 mm ± 0.236. In the latter case, Lapp, et al.,[5] found values of 0.535 mm ± 0.211.

Physiological Factors

In regard to physiological factors, the effective diameters of the conductive airways for airflow are defined by the surfaces of the mucous layers. In normals, the mucuous layer on the larger conductive airways is believed to be only about 5 μm thick[6] and decreases with airway size. In terminal bronchioles, it may be only 0.1 μm thick.[7] Hence, the reduction in air-path cross section by the mucous is negligible. On the other hand, in individuals with bronchitis, the mucous layer can be much thicker, and in some locations it can build up and partially or completely occlude the airway. Air flowing through partially occluded airways will form jets, which will probably cause increased deposition of particles in small airways by impaction and turbulent diffusion.

Other Effects

No discussion of the deposition of inhaled aerosols would be complete without consideration of the influence of airborne contaminants on the lungs of the people inhaling the particles. Inhaled irritants can affect the fate and toxicity of the inhaled particles by altering airway caliber, respiratory function, clearance function, and/or the function, survival, and distribution of the cells which line the airways. Any reduction in cross section in the larger bronchial airways increases flow velocities and should, therefore, increase particle deposition by impaction. Tracheobronchial particle deposition is significantly greater in cigarette smokers than in nonsmokers,[8,9,10] presumably because of the bronchoconstrictive properties of cigarette smoke.

While some normal cigarette smokers have increased bronchial deposition, the increase is relatively small compared to that in individuals with clinically defined, chronic bronchitis.[8,11,12] Greatly increased tracheobronchial particle deposition has also been seen in some asymptomatic asthmatics.[8]

EXPERIMENTAL DEPOSITION DATA

Total Deposition

Relatively few attempts have been made to measure regional particle deposition in humans. A much larger number of studies have explored total deposition. For particles between 0.1 and 2 μm aerodynamic diameter, deposition in the conductive airways is generally very small in comparison to deposition in the alveolar regions, and total deposition approaches alveolar deposition. Total deposition as a function of particle size and respiratory parameters has been measured experimentally by numerous investigators. Many previous reviews of deposition have called attention to the very large difference in the reported results.[13-17]

Much of the discrepancy can be attributed to uncontrolled experimental variables and poor experimental technique. The major sources of error have been described by Davies.[3] Data from studies performed with good techniques and precision all appear to show the same trend, with minimum deposition at about 0.5 μm diameter.

The deposition data in Figure 2 by Chan and Lippmann[18] and Stahlhofen, et al.,[19] were based on external in vivo measurements of γ-tagged particle retention. This technique was also used by Swift, et al.[20] for tests in the 0.03 μm size range.

Head Deposition

Some inhaled particles deposit within the air passages between the point of entry at the lips or nares and the larynx. The fraction depositing can be highly variable, depending on the route of entry, the particles' sizes, and the flow rates. In most cases, the nasal route is a more efficient particle filter than the oral, especially at low and moderate flow rates. Thus, people who normally breath part or all of the time through the mouth may be expected to deposit more particles in their lungs than those who breathe entirely through the nose. During exertion, the flow resistance of the nasal passages causes a shift to mouth breathing in almost all people.

Deposition in the Tracheobronchial Zone

Figure 3 shows in vivo measurements of tracheobronchial (T-B) deposition of normal healthy humans by Lippmann and co-workers,[8,15,18,21,22] and Stahlhofen, et al.[19] T-B deposition for a given particle size varies greatly from subject to subject among nonsmokers, cigarette smokers and patients with lung disease.[18] Average T-B deposition is slightly elevated in smokers and greatly elevated in the lung-disease patients.[8,12] However, among normals and nonbronchitic smokers, each individual has a characteristic and reproducible relationship between particle size and deposition. T-B deposition includes both deposition by impaction in the larger airways and deposition by sedimentation in the smaller airways. Impaction deposition predominates for large particles (diameter larger than 3 μm) and high flow rates (more than 20 L/min), while sedimentation deposition becomes a larger fraction of a diminishing T-B component for smaller particles and lower flows.

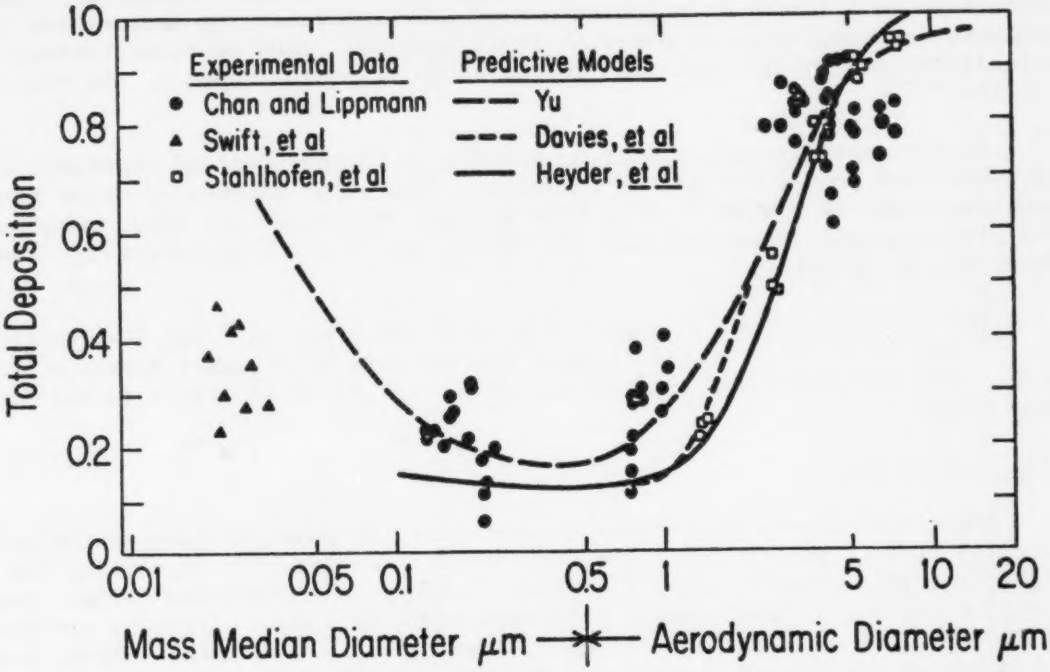

Figure 2. Experimental total respiratory tract deposition data from radioaerosol studies, and predictive models for total deposition.

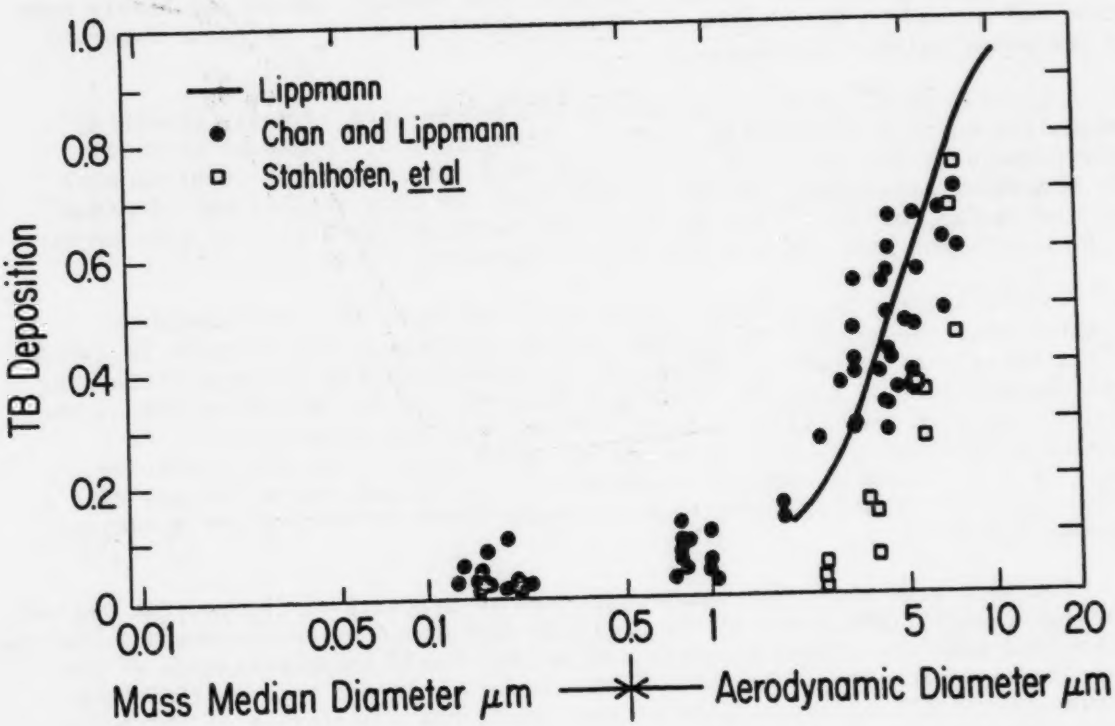

Figure 3. Experimental tracheobronchial (T-B) data for radioaerosol studies.

For deposition within the tracheobronchial zone, the pattern of deposition within hollow airway casts made from normal human lungs demonstrates that the airway bifurcations accumulate a disproportionate share of the deposits.[23,24] Furthermore, the density of the surface deposition on the bifurcation regions appears to correspond close with the incidence of primary cancer sites. The largest numbers of human lung cancers are found in lobar bronchi. Among the lobar bronchi, the largest numbers are found at the right upper bronchus and the smallest in the right middle bronchus. Figure 4 shows cast deposition data for the lobar bronchi for various particle sizes and flow rates. While the absolute amounts of deposition vary considerably with particle size and flow rate, the relative amounts on the various lobar bronchi remain relatively constant and appear to be closely associated with the cancer incidence reported in the pathological literature.

Figure 5 shows alveolar deposition values obtained in mouth-breathing inhalation tests on nonsmoking normals. These data are based on external measurements of the retention of γ-tagged particles after the completion of the bronchial clearance. It can be seen that the data of Chan and Lippmann[18] and Stahlhofen, et al.,[19] are in good agreement, and both sets of data appear to be consistent with the earlier data of Lippmann and Altshuler.[22]

Figure 6 shows an estimate of the alveolar deposition that could be expected when the aerosol is inhaled through the nose. The estimate is based on the difference in head retention during nose-breathing and mouth-breathing from the analysis of Lippman.[15] It can be seen that for mouth-breathing, the size for maximum deposition is about 3.5 μm, and that about half of the inhaled aerosol of this size deposits in this region. For nose-breathing, there is a much less pronounced maximum of about 25 percent at 2.5 μm, with a nearly constant alveolar deposition averaging about 20 percent for all sizes between 0.1 and 4 μm.

Figure 6 also shows the sampler acceptance criteria of the British Medical Research Council (BMRC) and of the American Conference of Governmental Industrial Hygienists (ACGIH). These criteria define the cutoff characteristics of the precollectors preceding respirable dust samplers. It can be seen that both provide reasonable approximations of the cutoff characteristics of the human conductive airways, at least those of nonsmoking normals. The alveolar deposition calculated on the basis of the International Commission on Radiological Protection (ICRP) Task Group's model[17] departs significantly from the deposition observed in reliable experimental studies.

The 1966 Task Group report has been widely quoted and used within the health physics field. One of the significant conclusions of the Task Group study was that regional deposition within the respiratory tract can be estimated using a single aerosol parameter, the mass median diameter. For a tidal volume of 1450 cm^3, there were relatively small differences in estimated deposition over a very wide range of geometric standard deviations ($1.2 < \sigma g < 4.5$).

PARTICLE RETENTION

Particle retention is a time-dependent variable that is the difference between the amount of aerosol deposited and the amount cleared. For a given

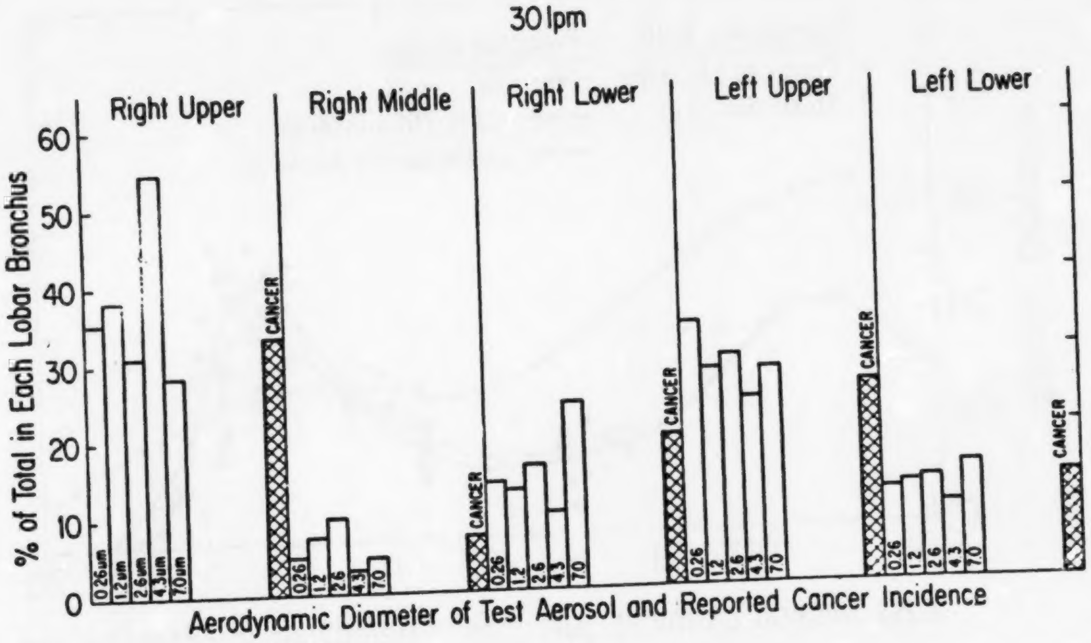

Figure 4. Percentage of total particle deposition within the five lobar bronchi of the cast which occurs within each lobar bronchus, at a flow rate of 30 L/min, compared with the reported percentage of total lobar bronchial carcinomas which originate within each lobar bronchus. Data on cancer sites are from Schlesinger and Lippman.[24] With permission of Academic Press.

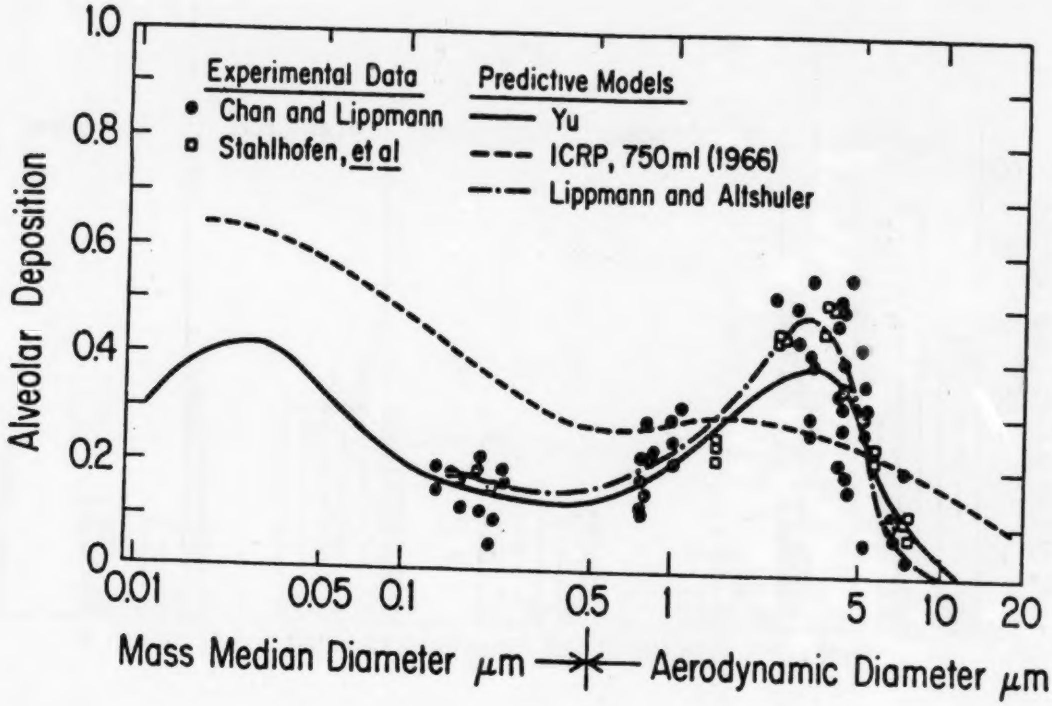

Figure 5. Alveolar deposition data from radioaerosol inhalation studies, and predictive models for alveolar deposition.

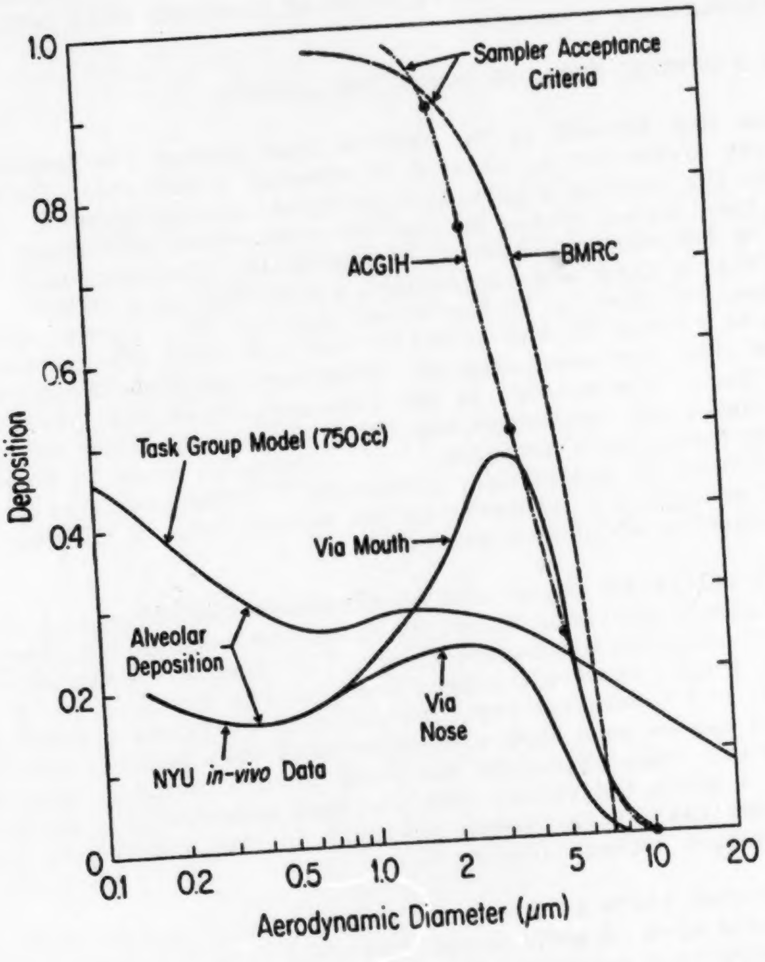

Figure 6. Comparison of sampler acceptance curves of BMRC and ACGIH with alveolar deposition according to an ICRP Task Group,[17] and from the experimental New York University deposition data of Figure 5.

individual, rates of clearance vary greatly from region to region within the respiratory tract. This variation was a major basis for the characterization of functional zones described earlier. In two of these zones--the ciliated nasal passages and the tracheobronchial tree-clearance in normal individuals is completed in less than 1 day. In the alveolar zone, clearance proceeds by slower processes, most of which vary considerably with the composition of the particles. A detailed discussion of alveolar clearance will follow the discussion of mucociliary clearance.

CLEARANCE OF PARTICLES FROM THE CONDUCTING AIRWAYS

Particles that deposit in the airways that conduct the inspired air to the respiratory tissue may be cleared by several mechanisms. The most important mechanism for insoluble particles is mucociliary clearance. Particles deposited on the surface of the mucous are transported proximally as the mucous is propelled by the rhythmic beating of the cilia. However, soluble particulates, depending on their physicochemical properties, may either be incorporated into the mucous, be taken up by the airway epithelium, or pass through the epithelium to be cleared by the bronchial and pulmonary circulations. It has been suggested that some insoluble particles may penetrate the mucous and enter epithelial cells.[25] Conversely, it has been postulated that particles from interstitial spaces and lymphatics may enter the airway lumen and be removed subsequently by mucociliary activity.[26,27] A recent review by Wanner emphasizes the clinical aspects of mucociliary transport.[28] This review will concentrate on the role of mucociliary transport in the normal lung as a defense mechanism through its clearance of inhaled particles.

Stationary collimated scintillation detectors can be used to obtain measurements of thoracic particle retention which are essentially independent of the particle distribution within the thorax.[8,19] Figure 7 shows particle retention curves for inert, insoluble tagged monodisperse particles in the hours following a 1 minute inhalation exposure for four different nonsmoking, healthy human males. It can be seen that clearance rates vary widely, even when the amounts cleared are comparable. On the other hand, clearance rates are quite reproducible in a given individual when the same particle size is inhaled, and they vary systematically with changes in particle size and the concomitant changes in deposition pattern (Figure 8).

It is clear that there is a wide variation in the rate at which seemingly healthy individuals clear deposited radioaerosols from the lungs. In persons with chronic obstructive pulmonary disease, there is a somewhat wider variation. However, the within-subject variation is greatly increased.[29] This suggests that loss of control of mucociliary transport could cause and/or result from chronic obstructive lung disease.

FACTORS AFFECTING MUCOCILIARY TRANSPORT

Cigarette Smoke

The studies reporting effects of smoking on mucociliary transport have been very confusing because of the widely varying effects that tobacco smoke produces.[30]

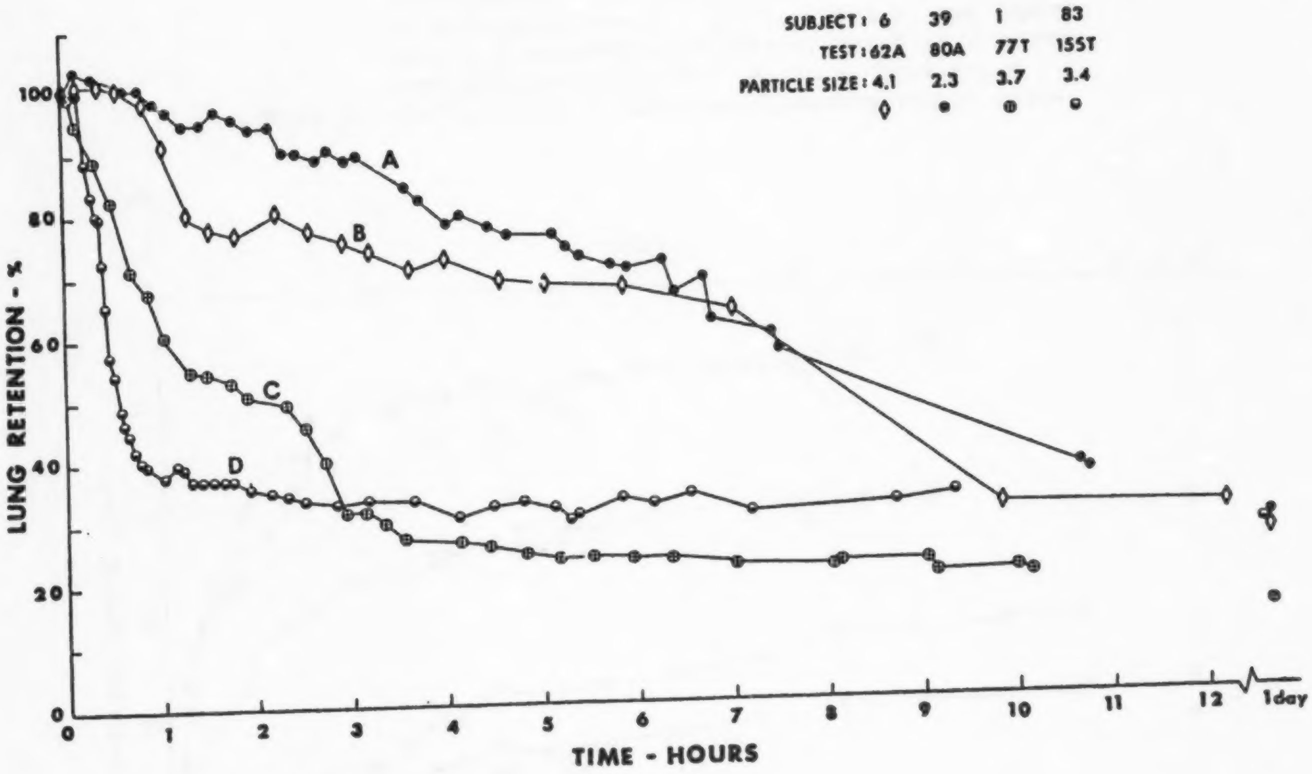

Figure 7. Retention of γ-tagged, monodisperse ferric oxide microspheres as a function of time following a 1-minute inhalation exposure via mouthpiece, for four healthy nonsmoking males.

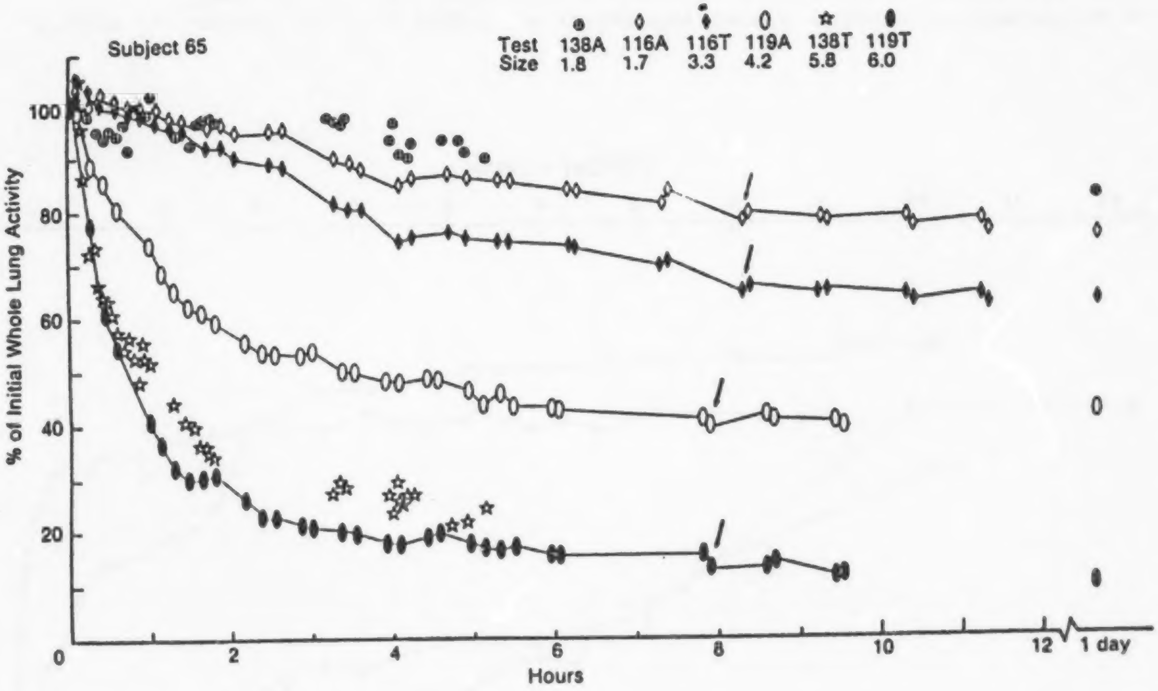

Figure 8. Retention of γ-tagged monodisperse ferric oxide microspheres of various particle sizes for a single nonsmoking male participating in a series of inhalation tests. The fraction of the inhaled particles cleared by mucociliary clearance varies systematically with particle size, but the effective duration of the bronchial clearance phase is relatively independent of size. With permission from the American Medical Association.

In man, the immediate response to normal smoking has been either an increase in tracheobronchial clearance, or no effect.[31,32,33] In the donkey, low exposure levels of cigarette smoke accelerated clearance,[34] but impairment of clearance was observed at higher levels.[34] The relative increase in transport is greater in the small airways.[35] This may be due partly to the adrenergic stimulation caused by tobacco smoke. Chronic smoking appears to have a more variable effect on mucociliary transport. This is due to variation in dosage, degrees of individuals' susceptibility to tobacco smoke, the diversity of studies undertaken, and the small number of subjects involved. Yeates, et al.,[32] have shown that tracheal transport rates were within normal limits in nine smokers studied. Although rapid clearance has been observed in some long-term smokers, impairment of large airway clearances has been suggested by Albert, et al.,[1] Bohning, et al.,[36] Camner, et al.,[37] and Lourenco, et al.[38] Pavia, et al.,[39] and Thomson and Pavia[11] were unable to demonstrate any effect on of long-term smoking on bronchial clearance. Albert, et al.[1] showed that some heavy cigarette smokers had long overall bronchial clearance times, which could be interpreted as slow clearance in small airways. Faster clearance has been observed in smokers studied three months after cessation of smoking.[40] Chronic high-level exposure to cigarette smoke has been found to severly impair bronchial clearance in the donkey,[41] with recovery almost complete within a few weeks after cessation of smoking.

Sulfur Oxides

In vivo exposures to sulfur dioxide at concentrations that have been measured in ambient air are not likely to affect mucociliary clearance. At higher levels, more typical of some occupational exposures, effects have been observed. Wolff, et al.,[42] exposed nine nonsmokers to 5 ppm (13 mg/m^3) of SO_2 for three hours after an albumin aerosol tagged with ^{99}Tc. The tracheobronchial mucociliary clearance of the tagged aerosol was essentially the same as in control tests, except for a transient acceleration at one hour after the start of the SO_2 exposure. In further tests by Wolff, et al.,[43] it was shown that exercise accelerates bronchial clearance, and 5 ppm of SO_2 during exercise speeds clearance significantly beyond that produced by the exercise alone.

High concentrations of SO_2 can slow bronchial clearance. In donkeys, thirty-minute exposures to SO_2 via nasal catheters produced delayed bronchial clearance and severe coughing and mucus discharge via the nose when the concentration exceeded 300 ppm.[44] Mean residence times following exposures of 53 to 300 ppm were not significantly different from control levels. The one test performed at a lower concentration (27 ppm) produced an acceleration in bronchial clearance, which would be consistent with the clearance accelerations seen by Wolff et al.,[85,98] with 5 ppm exposures. These results--an acceleration at low concentrations and a slowing at higher levels of exposure--are similar to those produced by cigarette smoke.

Fairchild, et al.[45] showed that four-hour exposures to high concentrations of sulfuric acid (15 mg/m^3 of 3.2 μm CMD droplets) reduced the rate of ciliary clearance of a tagged streptococcal aerosol from the lungs and noses of mice. At concentrations of 1.5 mg/m^3 of 0.6 μm CMD droplets, there were no significant effects.

Schlesinger, Lippmann, and Albert[46] demonstrated that one-hour exposures to submicrometer sulfuric acid mist at concentrations in the range of 200 to 1000 $\mu mg/m^3$ produced transient slowings of bronchial mucociliary particle clearance in three of four donkeys tested. In addition, two of the four animals developed persistently slowed clearance after about six acid aerosol exposures. Similar acid exposures had no effects on regional particle deposition or respiratory mechanics, and corresponding exposures to ammonium sulfate had no measurable effects. In subsequent tests, the two animals showing only transient responses, and two previously unexposed animals, were exposed one hour daily five days per week, to submicrometer sulfuric acid mist at 100 $\mu g/m^3$.[47] Within the first few weeks of exposure, all four animals developed erratic clearance rates, i.e., rates that on specific test days were either significantly slower than or significantly faster than those in their preexposure period. However, the degree and the direction of change in rate differed to some extent in the different animals. The two previously unexposed animals developed persistently slowed bronchial clearance during the second three months of exposure and during four months of follow-up clearance measurements, while the two previously exposed animals adapted to the exposures in the sense that their clearance times fell consistently within the normal range after the first few weeks of exposure.

The sustained, progressive slowing of clearance observed in two initially healthy and previously unexposed animals is a significant observation, since any persistent alteration of normal mucociliary clearance can have important pathological implications.

Short-term inhalation exposures of healthy human volunteers to sulfuric acid mist produced consistent results. Ten healthy nonsmokers inhaled 0.5 μm ($\sigma_g = 1.9$) H_2SO_4 at 0 (control), 110, 330, and 980 $\mu g/m^3$ for one hour via nasal mask in random sequence on four separate days. Respiratory mechanical function was assessed before and ½, 2 and 4 hrs after the H_2SO_4 exposure. A ^{99}Tc tagged Fe_2O_3 aerosol (7.5 μm aerodynamic diameter, $\sigma_g \leq 1.1$) was inhaled ~ 10 min before each H_2SO_4 exposure, with flow rate = 1.0 L/s, tidal volume = 1.0 L and respiratory rate = 15/min. Thoracic retention of the deposited radioactivity was monitored using collimated scintillation detectors. A tracheal probe was used to determine the tracheal mucociliary transport rates (TMTR's) of local concentrations of activity. Bronchial mucociliary clearance was markedly altered in a dose dependent pattern in six of the individuals and in the group as a whole. Exposures to 110 $\mu g/m^3$ resulted in a significant acceleration in mucociliary clearance (group mean tracheobronchial clearance half-time ($TB_{\frac{1}{2}}$) decreased from 80 to 50 min.) Exposures to 980 $\mu g/m^3$ caused a significant transient slowing of clearance, with the $TB_{\frac{1}{2}}$ increased to 118 min. In contrast, there were no significant changes in TMTR, or in indices of ventilatory mechanics (V_{25}, R_{aw} and distribution of ventilation by N_2 washout.) The four individuals whose clearance times were not significantly affected by these H_2SO_4 exposures had the fastest bronchial clearance among the ten, and they were each given an additional test with a 1,000 $\mu g/m^3$ H_2SO_4 exposure preceding the tagged Fe_2O_3 aerosol. Three of them responded with threefold or greater increases in $TB_{\frac{1}{2}}$. Thus, 9 of 10 subjects had substantial changes in bronchial clearance times following H_2SO_4 exposures.[48]

ALVEOLAR CLEARANCE

Once a material is deposited on the respiratory epithelium of the alveolated spaces, clearance takes place by means of two general kinds of processes. These processes can be termed absorptive and nonabsorptive. Most likely, the processes occur together or with temporal variations.

The most widely-accepted nonabsorptive clearance mechanism in the alveolar region is phagocytosis by macrophages.[49] Despite the common acceptance of phagocytosis and subsequent cell removal as the dominant nonabsorptive clearance mechanism, it has, so far, not been adequately described in quantitative terms. For example, there are conflicting data on the effect of particle size on phagocytic uptake by rabbit alveolar macrophages. Holma[50] found uptake to decrease with particle size, while Hahn, Newton, and Bryant[51] found the opposite. Holma's smallest particles were 1.5 μm, while Hahn's largest were 2.2 μm. The results could be consistent if uptake peaked at 2 μm. More data are clearly needed to clarify this issue.

The clearance pathways for phagocytosed particles remain controversial. It is generally agreed that macrophages ingest particles and transport them proximally on the bronchial tree to be swallowed. However, there is considerable disagreement on the predominant pathway between the alveoli and the bronchial tree. There are proponents for an interstitial route, while others favor a continuous proximally moving surface film which draws the cells onto the ciliated surface at the terminal bronchioles.

A chronic phase of clearance, characterized by the appearance of particles within macrophages of the connective tissue compartment of the lungs, begins from one to three weeks after exposure, according to Sorokin and Brain.[52] The extent of such sequestering of particles increases slowly in the subsequent weeks and months. For several months, a far greater percentage of alveolar than of connective tissue macrophages store inert particles, but ultimately whatever remains uncleared from the lungs resides in the connective tissue. The fate of cytotoxic particles may differ from that of relatively inert particles.

The internal redistribution of particles retained within the lung is an important factor in determining the site of damage. Redistribution is apparent in the centrilobular accumulation of pigment seen on the cut surfaces of human sections.[53,54,55] Such a focal accumulation of particles can also influence their retention and pathogenic potential.

For low mass concentrations of short fibers that were neutron activated, Morgan, Evans, and Holmes[56] found no significant differences between amphibole and chrysotile asbestos in *in vivo* retention in the rat. Autoradiographs of lung sections indicated that the initial deposition was uniform right out to the lung periphery, while over a few months the fibers accumulated in foci that were mainly subpleural.

In subsequent experiments, Morgan, Holmes, and Talbot[57] administered radioactive asbestos to rats by inhalation. After exposure, the animals were sacrificed serially and the lungs were subjected to bronchopulmonary lavage. Initial washes were made with a balanced salt solution that removed free fiber and cells from the conducting airways. Subsequent washes were made with physiological saline, which recovered cells that originally were in the alveolar spaces. The number of cells and the amount of fiber recovered in each wash were measured. About 20 μg of fiber was deposited in the lung and appeared to have no significant effect on either the number or size of free cells in the lung. Uptake of fiber by alveolar macrophages was effectively complete after 24 hours. Analysis of the results suggests that fibers much longer than the diameter of the alveolar macrophage (about 12 μm) find their way into the alveolar wall from where they cannot be recovered by lavage. This process is complete within two weeks of exposure.

Wright and Kuschner[58] used short and long asbestos and manmade mineral fibers in intratracheal instillation studies in guinea pigs. With long fibers, all of the materials produced lung fibrosis, although the yields varied with the materials used. However, with equal masses of short fibers of equivalent fiber diameters, none of the materials produced fibrosis.

Short fibers are less damaging, it appears, because they can be fully ingested by macrophages.[59] Longer fibers can rupture the macrophage membrane, which can result in release of digestive enzymes and/or loss in mobility.[60]

Most inhalation studies have been performed with aerosols containing both short and long fibers, and it should be noted that responses may be related primarily to the initial burden and/or persistence of the longer fibers. For example, Middleton, Beckett, and Davis[61] exposed rats to U.I.C.C. (International Union Against Cancer) standard reference samples of amosite, crocidolite, and chrysotile A at concentrations of 1, 5, and 10 $\mu g/m^3$, and sacrificed them serially over the next four months. They found less retention of chrysotile than of the amphiboles, and the clearance of the amphiboles appeared to be dose related.

TRANSLOCATION OF PARTICLES

Particles that penetrate the alveolar surface can migrate through the lymphatic drainage system to pleural, hilar, and tracheal lymph nodes. However, the migration is very slow. Ferin[62] found negligible accumulation of titanium dioxide in the lymphatics at 25 days. Sorokin and Brain[52] reported that significant buildup of ferric oxide particles in the lymphatics did not take place until nearly a year after the aerosol exposure. On the other hand, Thomas[63] reported that the concentration of radioactive particles in the lymph nodes exceeds the lung concentration at several months after the end of the inhalation. Ferin[64] found that the fraction of lung dust cleared via the lymphatics increased with total lung burden of dust.

Materials deposited by inhalation can usually be found in measurable quantities in other organs. In most cases, the presumed pathway is the bloodstream following gradual dissolution in lung fluids and diffusion into pulmonary capillaries. Absorption presumably depends on materials' being mainly in a monomeric state or, to a lesser extent, in polymeric forms of small dimensions.[65] Some *in vitro* solubility models[66,67] have proven useful in predicting *in vivo* clearance rates, but at other times provide inconsistent or erroneous estimates. Further work is needed to improve these models.

ALVEOLAR CLEARANCE KINETICS

The clearance of particles deposited in the alveolar region proceeds in several temporal phases which usually can be described by a series of exponentials. Each presumably corresponds to a different clearance mechanism.

Casarett[68] proposed that the earliest alveolar phase, with a half-time measured of weeks, is generally associated with phagocytic clearance, while a slower phase, with a half-time in months or years, is generally associated with solubility. The ICRP Task Group model[17] does not include the initial alveolar phase. Casarett attributes the omission to the task group's overreliance on data from studies in which the phase was absent because of the cytotoxicity of the dusts used. Jammet, et al.[69] showed that for hematite dust, a clearance phase with a half-time of 10 to 12 days is normally present in the cat, rat, and hamster preceding a slower phase with a half-life exceeding 100 days. The 10-to-12 day phase disappeared when the animals were exposed to sufficient plutonium,[70] silica dust, or carbon dust,[71] while the half-time for the slower phase was relatively unaffected.

Considering the recognized importance of the alveolar retention of relatively insoluble particles in the pathogenesis of chronic lung disease, it is somewhat surprising that examination of the literature yields virtually no useful data on the rates or routes of alveolar particle clearance in man.

The only experimental studies on human alveolar clearance are those of Albert and Arnett[72] and Morrow, et al.[73,74]

In the Albert and Arnett study, eight normal human males inhaled neutron activated metallic iron particles. For three subjects, there was sufficient residual activity after the completion of the bronchial clearance for continued measurement of retention. For a 32-year-old nonsmoking male, and a 27-year-old male who was a moderate smoker, the postbronchial clearance occurred in two phases, a fast phase lasting about one month and a much slower terminal phase. The faster phase was missing in a 38-year old, two-pack-a-day cigarette smoking male with chronic cough. While it is not possible to draw firm conclusions from these limited data, they are consistent with the recent findings of Cohen, et al.,[75] who studied the alveolar clearance rates of magnetic particles in nine nonsmokers and three smokers, using an external magnetometer for the particle retention measurements. The clearance rates in all three smokers were much lower than in any of the nine nonsmokers. Thus, it appears that the fast alveolar phase can be detected in man and that cigarette smoking may increase dust retention beyond the retention of the smoke particulates themselves. Low doses of cigarette smoke have been shown to inhibit macrophage phagocytosis.[76]

The only other experimental human inhalation studies of alveolar clearance under controlled conditions, as noted, are those of Morrow, et al. In an initial study,[74] these authors had four normal individuals inhale a $^{54}MnO_2$ aerosol with a median size of 0.9 μm, a geometric standard deviation of 1.75, and a concentration of 4 mg/m^3. The aerosol was inhaled for 20 to 30 min in a breathing pattern in which four normal inhalations alternated with a maximal inhalation. Measurements made more than 48 hours after the inhalation showed a single clearance phase for all four individuals, with biological half-times that varied only from 62 to 68 days.

In the additional human studies of Morrow, et al.,[73] using several different aerosols, alveolar clearance rates were also reported in terms of a single exponential. The half-times varied with the composition of the particles. Half times of 65, 62, and 35 days were found for $^{54}MnO_2$, Fe_2O_3 labeled with ^{51}Cr, and polystyrene ^{51}Cr respectively. The half-time for the polystyrene particles may have been relatively short because it was based on less than 14 days of measurements and, therefore, may have been more influenced by a rapid initial rate of alveolar clearances than were the half-times for the iron and manganese oxides, which were followed for periods between 45 and 120 days.

ALVEOLAR RETENTION OF MINERAL DUST

The pneumoconioses are chronic lung diseases with long latent periods, and radiographic changes and/or functional decrements that result from the accumulation of respirable dust in the deep lung regions cannot be detected for many years after the exposures that produced them. Furthermore, the latent period for the pneumononioses tends to increase as the exposure level decreases. For example, evidence for disease may appear within 15 years when exposure levels are very high, but not for more than 30 years when exposure levels are much lower.

The long latent period makes it very difficult to establish causal relationships between exposure and response, since the exposure conditions at the time the disease is diagnosed may bear little relation to those present earlier.

SUMMARY

Particle deposition efficiencies and patterns within the respiratory tract are highly variable. They are determined by the air path dimensions and configurations in the individual, the pattern and depth of the respirations, and the characteristics of the airborne particles. The bronchial airways vary considerably in size among normal, nonsmoking adults; these variations are even greater among smokers without clinical disease symptoms.

The distribution of the particles' deposition sites depends strongly on their aerodynamic diameters. In normal humans, inhaled nonhygroscopic particles that deposit in the head and ciliated airways of the lungs by impaction are concentrated on a small fraction of the surface. Cigarette smoking and bronchitis produce an increase in bronchial airway deposition. For nonhygroscopic aerosols with aerodynamic diameters between 10 μm and 1 μm, an increasing fraction remains airborne as particle size decreases, and is exhaled. Total respiratory tract deposition in normals reaches a minimum of about 10-20 percent for particles between 0.2 and 1 μm and increases for particles smaller than 0.2 μm. The major factor determining the probability of deposition of the smaller particles is their transfer from tidal to reserve air, and they may remain airborne within the reserve and residual air for a number of breaths before actually depositing.

The dominant deposition mechanisms are impaction (for particles larger than 1.5 μm), sedimentation (about 0.5 to 1.5 μm) and diffusion (smaller than 0.5 μm). Deposition by sedimentation and diffusion produce relatively uniform surface deposits in small bronchioles, alveolar ducts, and alveolar sacs. Hygroscopic particles grow rapidly within the warm, moist airways, becoming dilute aqueous droplets that can be three to five times the diameter of the inhaled particles.

For particles soluble in respiratory tract fluid, systematic uptake may be relatively complete for all deposition patterns, and there may be local toxic and/or irritant effects. On the other hand, slowly soluble particles depositing in the head beyond the anterior nares or on ciliated tracheobronchial airways will be transported by the surface flow of respiratory-tract fluid to the glottis and will be swallowed within one day or less.

Mucociliary transport rates are highly variable, both along the ciliated airways of a given individual and between individuals, depending on the thickness and character of the secretions and the number and beat rate of the cilia. Effective fluid movement depends on the coupling of the ciliary motion within the sol layer with the more viscous overlying layer. A moderate increase in secretions, such as those produced by a few cigarettes or therapeutic dosages of some adrenergic drugs, can result in acceleration of mucus transport. Larger dosages or long-term exposures, which can cause an increase in the number and/or size of the secretory cells and glands, can produce mucus layers too thick to be propelled effectively by the cilia, and clearance stasis and periodic retrograde flow can result.

Mucociliary transport rates decrease distally within the bronchial tree. The total duration of bronchial clearance in normal humans varies from about 2.5 to 20 hours. The changes in clearance rates produced by drugs, cigarette smoke, and various occupational dust exposures, can increase or decrease these rates by large factors, sometimes by an order of magnitude. However, the importance of alterations of mucociliary transport in the pathogenesis of chronic lung disease is not yet clear.

Particles deposited in nonciliated airways have large surface-to-volume ratios, and therefore, significant clearance by dissolution can occur for materials generally considered insoluble. They can also be cleared as free particles, either by passive transport along surface liquids or, after phagocytosis, by transport within alveolar macrophages. If the particles penetrate the epithelium, either bare or within macrophages, they can be sequestered within cells or enter the lymphatic circulation and be transported to pleural, hilar, and more distant lymph nodes. In most cases, the quantitative aspects of these clearance pathways vary with the composition of the particles and are poorly understood. Nontoxic, insoluble particles are cleared from the alveolar region in a series of temporal phases. The earliest, lasting several weeks, appears to involve the clearance of phagocytosized particles via a bronchial tree. The terminal phases appear to be related to solubility at interstitial sites. The effects of infectious diseases, cigarette smoking, and other environmental factors on the kinetics of alveolar clearance are not known adequately.

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FATE OF INGESTED PARTICULATES

by

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ABSTRACT

People consume many solid particles everyday through food, water, and beverages. A review of the literature shows that while there is no mass penetration of particles through the walls of the gastrointestinal tract, there is considerable evidence that mineral fibers and other durable particulates do transmigrate from the G.I. tract to other parts of the body. Several mechanisms for particulate penetration have been postulated and the mechanism may well be different for different types of materials and for different sizes of particles. Penetration of asbestos fibers is a relatively rare occurrence and is estimated to be on the order of 1 fiber in 10,000. Once in the body, some fibers and other particulates may be accumulated in certain tissues but many are cleared and eliminated through the urinary tract.

Particulates form a general category which is not very well defined. In the drinking water industry we loosely classify the particulate component as pieces of material of varying composition ranging up to 100 micrometers in size. The finding of particles larger than 100 micrometers (0.1 millimeter) in publicly supplied drinking water usually brings vigorous complaints from the consumer. The question of the lower limit of the size of particulates has largely been ignored. In the present analytical techniques available for water, particles smaller than 0.1 micrometer are not considered. The question of what constitutes a particulate in food is far more difficult than when considering water. Analyzing food for particulates is an extremely difficult task.

If particulates swallowed with food, beverages, and water do not migrate across the gastrointestinal mucosa of the alimentary canal, the question of whether any ingested particle could be a cancer risk would be greatly simplified. It is clear that the food and liquids one consumes everyday contain a high number of solid particles and by far the bulk of the nondigested material moves through the digestive system as illustrated in Figure 1 and is discharged

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*Presented by Dr. James Millette.

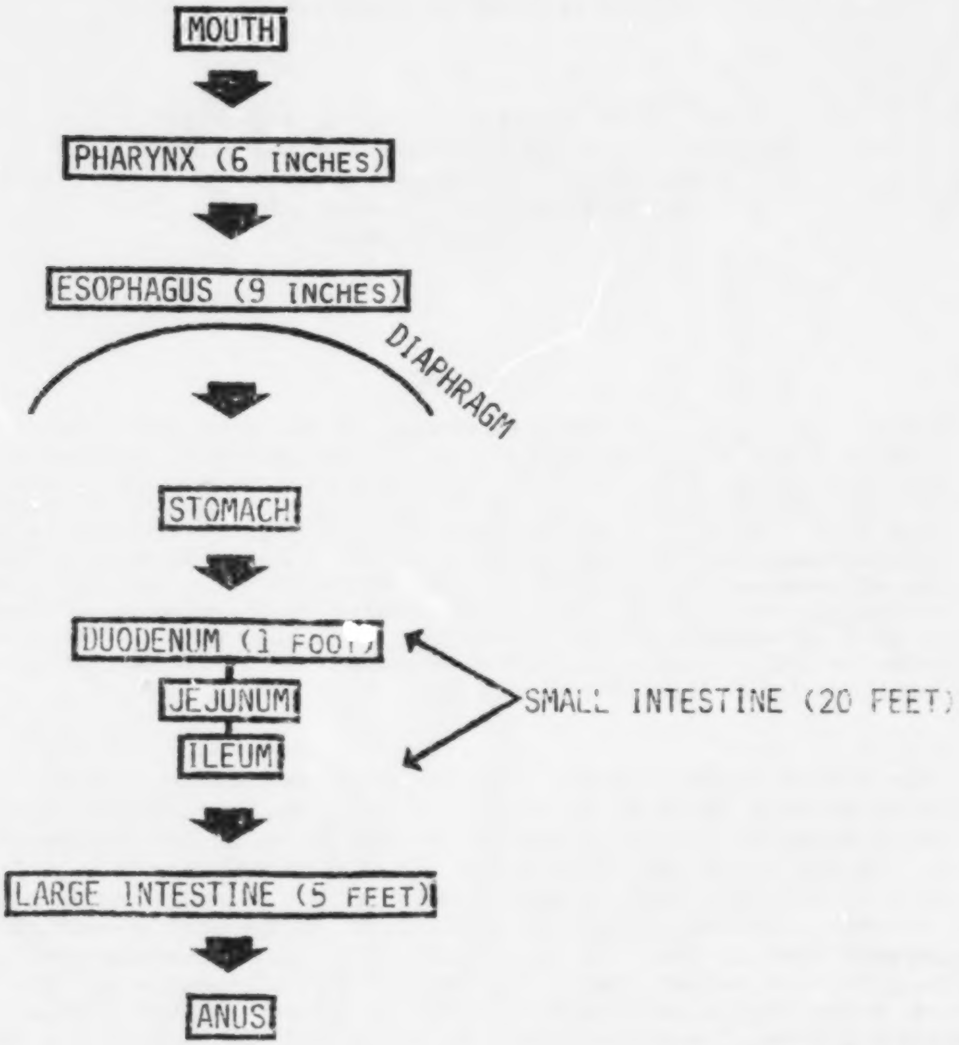
MOUTH
PHARYNX (6 INCHES)
ESOPHAGUS (9 INCHES)
DIAPHRAGM
STOMACH
DUODENUM (1 FOOT)
JEJUNUM
ILEUM
SMALL INTESTINE (20 FEET)
LARGE INTESTINE (5 FEET)
ANUS

Figure 1. Pathway of ingested material not assimilated by the gastrointestinal tract.

in the feces. While enroute on a normal trip, which may take a number of hours, some particles are coated with secretions, subjected to gastric juices, digestive enzymes, and drastic pH changes from pH2 to pH8. Only particles with certain sustaining traits can be considered candidates for direct transport through the GI wall. A more complete discussion of the activities of the digestive tract can be found in the appendix of this article.

Since asbestos and other durable fibrous materials placed directly in the peritoneum of animals have resulted in malignant neoplasms, the questions of which materials and how much can pass through the walls of gastrointestinal tract are particularly important.

The results of three laboratories' investigations on asbestos fiber penetration were described in one publication in 1974.[1] The paper reported no evidence of penetration of the G.I. mucosa by mineral fibers. Although a review of the studies shows their results to be suggestive, the studies themselves were not adequately designed to answer the full question of penetration. In the first laboratory, three studies were performed. The first investigation consisted of ten rats fed laboratory chow containing 5 percent ball-milled chrysotile for 21 months. After nine years storage in formaldehyde, tissue of the G.I. tract was prepared for electron microscopy. The digests of the tissues of the G.I. tract contained chrysotile fibers but it was impossible to tell whether the fibers had been in the mucosa or were a result of contamination. Unfortunately at the time the tissues had been preserved, tissue from the G.I. tract was not isolated from other tissues and no attempt was made to keep the formaldehyde solution that had been contaminated with asbestos containing fecal material from contaminating the other tissues with asbestos fibers. Fibers were found in the digests of the mesenteric tissue from both test and control animals but because the experimental procedure used unfiltered water and contaminated reagents, the findings could not be interpreted. No fibers were found in sections of intestines examined with electron microscopy but the amount of tissue searched was not given in the experimental details.

In a second study, still in the first laboratory, 20 unanaesthetized rats were given 400 mg of amosite or taconite mine tailings in 1 ml of suspension by gavage. Fibers were found in the digest of G.I. tract tissues in some but not all of the rats given amosite. No data were given as to the amount of tissue analyzed.

A third study incorporated finely ground amosite or taconite tailings into oleomargarine to obtain 10 percent amosite content or 20 percent taconite content. Fibers were found in the mesentery, lung, or kidney digests of some of the animals exposed to amosite or taconite but not in the digests of the control rat tissues. No data were given as to the actual amount of tissue examined so it is impossible to estimate the significance of finding fibers.

In the second laboratory studies reported in the 1974 article, the gut and other tissues of rats fed 0.2-0.4 percent crocidolite asbestos in butter for varying periods of time were examined only with optical microscopy. No evidence of fiber penetration was found. No data on the magnification used or amount of tissue surveyed were given.

Only partial data from the third laboratory was available for inclusion into the report. Chrysotile and crocidolite "properly ground" were mixed with butter to a 0.5 percent level by weight. Light microscopic examination of tissue sections showed no asbestos fibers that had penetrated. Electron microscopic examination of sections of small intestine and mesenteric lymph nodes also showed no signs of penetration. Again, no data were given as to the actual amount of tissue examined.

Together the results of the three laboratories suggest that there is no mass penetration of fibers through the gut wall, but because of the contamination of the first laboratory and lack of sensitivity in the second and third laboratories, the results in this 1974 article are not confirming evidence that durable fibers cannot transmigrate from the gastrointestinal tissues to the body.

A number of other investigators have addressed the question of digestive tract penetration by particulates. A number of their findings support the contention that particulate penetration is not a large scale event but does occur.

One of the first reports on the subject showed electron micrographs of asbestos fibers in many sites of the colonic epithelium and lamina propria of rats fed a 6 percent asbestos diet for 3 months.[2] Asbestos particles found in the tissue were up to 1 micrometer in length. No data were given on the size of the asbestos before feeding or the amount of tissue analyzed. The authors postulated that the particles had migrated through the mucous of the goblet cells into the cell itself and hence into the lamina propria.

In a human study, amphibole fibers were found in significant numbers in the lung, liver, and jejunum in 29 of 39 Duluth, Minnesota residents with oral exposure to mineral fibers in their drinking water lasting up to 15 years.[8] Among 21 control residents of St. Paul, MN and Houston, TX only two subjects were found to contain the amphibole type fiber, in each instance a single fiber from a single tissue site.

The methods of penetration of the digestive tract are postulated to be direct piercing of the cells by long fibers and pinocytosis of short fibers. According to Volkheimer,[9] particles in the nanometer size range can be channeled through the intestinal absorptive cell (enterocyte) by a pinocytosis-like process in minute bubbles with a diameter of up to 50 nm. Larger particles, whose diameter is well within the micrometer range, are suggested to be regularly incorporated by persorption. In this process particles are "kneaded" into the mucosa during their passage through the digestive tract. Volkheimer suggests that the particles pass between the epithelial cells into the subepithelial layer. It is easy to conclude that when durable fibrous materials are kneaded into the tissue some of the fibers would directly pierce the cells. Asbestos is known to be taken in by cultured cells.

Gross et. al.,[1] raised an important point in the question of penetration of the digestive tract by solid particles. If penetration of the GI mucosa by particulates did occur, the amount of stored material in the intestinal submucosa and in mesenteric lymph nodes would increase with age. Recent data suggest that many of the particles which have penetrated may be cleared from the body via the urinary tract. Amphibole fibers were found in the urine of persons who had been drinking unfiltered water containing the mineral.[10] Asbestos fibers have also been found in the urine of a baboon forced to ingest the material.[11] In most individuals a balance between fibers taken in and those cleared may be reached over time. Fiber concentration in tissue may increase with age but at a slower rate than fiber penetration of the digestive tract.

Nonasbestos materials also penetrate the digestive tract. In their mini-review of intestinal absorption of particulate matter, Le Fevre and Joel list a number of materials which have been reported to pass the intestinal barrier.[12] These include colloidal metals, latex spheres, polyvinyl chloride pellets, and iron filings. Volkheimer[9] reports using starch granules, cellulose particles, powdered rabbit hairs, charcoal, pollen and silicate crystals in his persorption studies. Cook reported finding nonfibrous particles of silica, diatom fragments, fibers of iron, titanium and glass of probable man-made origin. Attapulgite clay fibers have been reported in the urine of a person ingesting large doses for medical purposes.[13]

Little data were available on the rate of transfer of various solid materials through the digestive tract. Estimates of the passage rate for asbestiform fibers range from 1 fiber in 1,000[10] to 1 fiber in 10,000.[14] From the data provided by Cook and Olson[10] for 4 subjects ingesting unfiltered Lake Superior water over a number of years, the average concentration of fibers in the urine was 0.66×10^6 per liter. Compared with the average fiber content of Lake Superior water of about 100 million fibers per liter, this fact suggests that as many as 1 in 200 fibers crosses the digestive tract. This estimate assumes that a steady state between the number of ingested fibers and the number of fibers eliminated in the urine could occur so that the number of fibers in urine would represent the minimum number of fibers passing through the intestinal mucosa. As indicated by Cook and Olson, even the ratio of 1 in 1000 fibers passing seems remarkably large and may be modified by further measure.

The value of 1 fiber penetrating in 100,000 was determined using a rat study in which an asbestos pellet weighing approximately 20 mg was introduced into the stomach of rats by catheter.[14] The value of 1 in 100,000 may be an underestimate of what happens when fibers are ingested in water since the number of individual fibers available for penetration was dependent on the rats' ability to break up the pellet internally. The same researchers have reported the passage of both chrysotile and crocidolite fibers across the gastrointestinal wall and that the larger chrysotile fibers appear to pass at a higher rate than short fibers.[15]

If there is a balance achieved between intake of fibers and excretion through the urine, a maximum accumulated level of fibers in some tissues may be attained. It is interesting to note that the highest accumulation of chrysotile fibers in tissues (other than lung) reported by three independent researchers were all on the order of 10 million fibers per gram of tissue. See Table 1.

TABLE 1. MAXIMUM TISSUE FIBER CONCENTRATIONS REPORTED FOR CHRYSOTILE

Tissue	Fibers per gram	Chrysotile Exposure
Rat omentum[4]	8.6×10^6*	1% in diet for 6 weeks
Human liver[8]	10.9×10^6**	Unknown exposure over lifetime
Baboon kidney cortex[7]	7.8×10^6*	3×10^{13} fibers/kg in 9 days

*Corrected for control tissue concentration.

**Corrected for blank filter concentration.

In another study, a single suspension of chrysotile asbestos was injected into the stomachs of 10 anaesthetized rats.[3] Asbestos fibers were found in animals sacrificed 2 to 4 days later in the omentum (which surrounds the small intestine), blood, spleen and brain. The authors postulated that long fibers may pierce the gut like a needle, whereas pinocytosis may account for the absorption of smaller fibers. Fibers in one tissue were as long as 15 μm and one fiber in the blood was 23 um long. Some questions have been raised about the injection technique in that there might have been passage of fibers through the needle tract into the abdominal cavity.[1]

In a second experiment, the same researchers fed 10 rats a diet containing 1 percent chrysotile asbestos for 6 weeks.[4] Tissues were prepared using a procedure which included ashing, solubilization with dilute HCl, filtration, ashing the filter and dropping a 5 ul aliquot of tissue suspension on an electron microscope grid. Analysis of the tissues showed higher levels of asbestos in all tissues of test animals examined than in controls with the highest levels in the omentum (9.66×10^6 fibers per gram) followed by the brain, lung, liver, blood and kidney. Fiber lengths were up to 5 um. The authors concluded that ingested asbestos can penetrate the walls of the digestive tract but that when the amount of asbestos consumed by the rats in the 6-week period is considered, the amount found in tissues represent an extremely small portion.

One hour after amosite asbestos fibers suspended in saline were placed in an isolated segment of rat jejunum _in vivo_, the animal was sacrificed and fibers were found penetrating the epithelial surface.[5] Amosite fibers with diameters up to 1.4 um and visible lengths up to 30 um were seen in epithelial cells or in the lamina propria. All fibers seemed to enter the cell through its luminal surface. None penetrated the intercellular junctions. The authors concluded that penetration of the epithelial cells of the intestine directly through their cell bodies is at least one of the mechanisms by which asbestos fibers can gain access to the lamina propria of the intestine.

Fiber penetration of the digestive tract has also been documented in primates. Chrysotile asbestos fibers up to 35 um long were found in the kidney cortex of a newborn baboon fed asbestos containing milk formula for 9 days.[6,7] Statistically significant higher levels of fibers were found in the kidney (especially kidney cortex), lymph nodes, spleen, colon, and esophagus over control tissues. Five other tissues, stomach, liver, duodenum, cecum, and heart contained concentration of fibers not different from control tissues. The tissue was prepared using a procedure of low temperature ashing, solubilization with 1 percent acetic acid, filtration, ashing of the filter and placing 6 ul of tissue suspension on an electron microscope grid. There were fibers of various sizes found in the test animal tissues indicating, at least with the newborn, a range of sizes of asbestos fibers can penetrate.

This may indicate the upper level for chrysotile accumulation in tissue. Other particulates may accumulate to different levels and be regulated by different clearance mechanisms.

In summary, the research conducted on the penetration of the digestive tract by solid materials is sufficient to conclude that such penetration is not on a large scale but can and does occur. Research findings also suggest that while some fibers may be entrained in body tissue many are cleared through the urinary tract.

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APPENDIX

THE DIGESTIVE PROCESSES

Ingested material, whether it is considered food or foreign matter, must eventually either pass through the alimentary canal (gastrointestinal tract) or be assimilated by the body somewhat along the twenty seven or so feet of the canal.

Ingested material enters the GI tract through the mouth (and sometimes through the nasal cavity due to swallowing of material cleared from the respiratory tract). In the mouth, ingested material is acted upon by secretions from the Parotid, Submaxillary and Sublingual Salivary Glands. These secretions serve primarily to moisten the ingested material and mouth tissues, and to initiate the breakdown of ingested starches. Mastication serves to break up the material mechanically.

The ingested material then passes through the pharynx and into the esophagus, a short mucous-lined tube capable of producing wave like peristaltic motion that aids in moving material to the stomach. In the stomach lining, there are a number of specialized glandular cells whose function is to secrete digestive enzymes, buffers, hormones and hydrochloric acid. Ovoid parietal cells, in the lining, are stimulated by the vagus nerve, gastrin and histamine to secrete HCl into the lumen of the stomach. Mucous and alkaline fluids, secreted by the stomach lining, protect the stomach from being eaten away by the acid, which may range anywhere from pH 0.9-3.0 depending on the nature of the ingested material and the overall health of the individual. Some fluid absorption occurs in the stomach.

As the ingested material proceeds along its course into the duodenum of the small intestine, it is acted upon by alkaline pancreatic juices, $NaHCO_3$, insulin, glucagon, enzymes and proteins from the pancreas, bile from the liver and gall bladder; and secretin, duodenal juice, succus entericus and pancreozymin from the intestinal cells. The thick carpet of finger-like projections (villi) that line the small intestine allow for greater surface area and therefore more absorption. Most of the liquids, amino acids, sugars and other nutrients are taken up into the bloodstream via capillary beds among the villi and the hepatic portal vein (leading to the liver). This transport can occur by means of absorption, persorption or pinocytosis.

The non-assimilated portion of the ingested material proceeds to the large intestine where water, salt and glucose are absorbed from the fecal material. The fecal material then passes through the rectum and out the anus.

In man, the time period for the complete passage of non-assimilated ingested material will vary with each member, but usually ranges between 20 and 25 hours.

DISCUSSION ON THE ROUTES OF EXPOSURE: INHALATION, DEPOSITION AND CLEARANCE OF PARTICLES

REMARK (Dr. Gross): I am associated with the Industrial Health Foundation. I wish to comment on some of the statements that have just been made.

I have been a pathologist over the last 50 years. Half of that time was in hospitals where I spent a good deal of time studying the tissues of hospital patients who died as a result of their illness. One of the organs that was studied in great detail was the kidney.

I have always been impressed from a clinical point of view upon the exquisite ability of the circling unit of the kidney to hold back dissolved molecules of proteins that have a fairly high molecular weight and allow molecules of low molecular weight such as electrolytes to pass through.

When one considers the comparative size of a particulate, particularly a fiber, in relation to a micro-molecule such as albumin, which under normal conditions the circling membrane of the glomerulus (a unit in the kidney) holds back, there is an enormous difference and according to what Dr. Millette just said, quoting Dr. Cook's work, the passage of particulates through the renal circling membrane is not an unusual event. This is totally out of keeping with what we know of kidney function, the ability of the membrane of the glomerulus to hold back even dissolved molecules of appreciable size.

With regard to the passage of particles through the intestinal mucosa Dr. Millette quoted Volkheimer, who in his article claimed to find starch granules in the blood, in various tissues, and in the urine. These starch granules are 10 times the size of a red corpuscle and in order to pass, say through the intestinal wall into a blood vessel of any size it ultimately will have to pass through the capillary network that barely allows a single red corpuscle to pass through. Yet, we are supposed to believe that Volkheimer was able to demonstrate such huge particles in the urine.

As an example of the ability of the intestinal mucous membrane to hold back particles that happen to be in the intestinal ileum, I might mention that coal miners swallow a good deal of the dust that they inhale and in the swallowed coal dust are particles that are a fraction of a micron in diameter. If fibers, which are 1 micron in diameter, are capable of passing through the intestinal wall, then particles that are a small fraction of that size would have even a greater facility to pass through. Now, a coal miner may work in a coal mine for 30 years and every day he would swallow a fairly large amount of coal dust that he has inhaled and was brought up from his lungs, yet when one does autopsies, as I have done, on coal miners one does not see black discoloration of the lymph nodes. One rarely sees black spots in the liver and spleen, but that can be explained on the basis of lymphatic drainage from the lungs. But, one cannot see black lymph nodes in the mesentery, the lymph glands that drain the intestinal wall. One does not see that and one would see it if particles were capable of penetrating the intestinal wall.

You realize, of course, that I look with a very jaundiced eye on this presentation and I hope the audience will also be judicial in accepting this presentation.

REMARK (Dr. Kotin): I work for Johns-Manville Corporation. A couple of comments on the papers and then perhaps a few generalizations.

First, let me thank you, Dr. Rowe, for being sensitive enough to dedicate this session to Mearl Stanton. As a former associate of his at NCI there is no way we can overstate our debt to him and his associates. Also thanks for being good enough to stop me in the corridor to say I can talk for a few minutes if I want.

I am not sure that the case for penetration of the gut has been made by this presentation, but penetration of the gut does occur and I think that the criteria for penetration are probably not for this session.

I think that Dr. Millette might be well advised to know that both Doctors Cunningham and Pontefract were aware belatedly that the formaldehyde that they used for the fixation of tissues was loaded with asbestos fibers. Unfortunately it was filtered through asbestos and I think they are very candid in stating this, but in no way would I say that that necessarily throws out all of their data. I think quantitatively it might be challengable.

Again, I think the best thing that can be said about the Storeygard and Brown study is what Dr. Brown says himself. They were dealing with an exteriorized loop of intestine. He cannot be sure that he has got penetration or overlay on many of the sections, which I reviewed with him personally, so let us at least maintain the fact that maybe not these studies but others may very well substantiate the concept of penetration.

Dr. Lippmann, I think you might know that, and I am sure you are aware that Crystal and his associates at the Heart and Lung Institute are beginning to show, I think rather reliably and consistently, a role for the poly as well as for the macrophage in the fibrogenic capabilities. I think this has some relevance to the pathogenesis of a disease in people who are exposed to excessive amounts of asbestos.

Again, I have no new data to present because of the brevity of time, but let me restate a few verities that probably have been lost sight of and certainly I think have been given short shrift in the presentations.

Let me begin immediately by saying that the reality of asbestos-related disease has been amplified by the presentations at this meeting. I think at the very least you would have to have your sanity questioned to doubt the capability of excessive amounts of asbestos fibers to produce an array of asbestos related conditions. However, the disease-producing potential can not be divorced from accepted principles of pharmacology, toxicology, pathogenesis, pathology and clinical disease. Specifically, these principles include factors like dose response; multifactorial etiology in both disease development and disease natural history; the demonstration by several, including a person attending this conference, of a no adverse effect level in a very competently studied population; and the necessity for biological availability for host effect, which, of course, relates to the two earlier presentations. This includes things that have been discussed before; localization, retention, translocation, the dimension of the particles, the solubility of the particles, and I think all these principles, and one could go on listing many more, find expression and are all applicable to the problem of asbestos exposure and one that is particularly relevant to EPA. I do not envy EPA's responsibility in trying to address the issue of asbestos outside the work place. OSHA has by far the easier of it.

The patterns of asbestos-related disease in occupational settings are well known. The patterns of asbestos response in para-occupational settings, neighborhood studies, and family studies have not been shown and this does not mean that the positive studies are useless. Not at all. What they do clearly demonstrate is that even outside the workplace dose response has its universal application.

Perhaps a fourth pattern of exposure to asbestos-related disease, and this does put the EPA right in the middle of the circle, is a category, for want of a better term, I call "living with asbestos." This includes the school buildings. This includes asbestos as part of the earth's crust where it is indeed part of the potable water supply or part of the airborne suspended material as a result of wind and soil erosion. For this group, really, and I can only repeat what Dr. Rowe said, the data are pitifully little and really do not permit conclusions nearly as much as they permit what Sir McFarland Burnett called in his Nobel speech, "responsible speculation." The data do permit responsible speculation that the "living with" group does not have any asbestos-related disease as yet. One gives added credence to the negative data because you do have two marker situations, mesothelioma and a rather characteristic type of fibrosis. But this is not to say that the answer is in by a long shot.

Then you have the fourth category and this is the casual exposure and I mean casual not in the cultural sense. I mean casual in a quantitative sense; not the people in this room; you either work with asbestos or are using it in your laboratory or so on, but the next crowd that goes to see the Redskins play would predominantly be people casually exposed. Here, again, I think despite ongoing studies that have been comprehensive, yet inadequate, there is absolutely no evidence of an effect.

I would make two major closing comments. First, the assumption that all four classes are interchangeable in terms of the generalizations I have made is not true of course. The dosage of exposure is different, the co-factors differ and so on. So, I think one has to be very, very jealous in terms of the discipline in which one approaches each of these categories and tries to conclude from one to the other.

The second point I would like to make is that the four categories, again, in no way contradict the occupational information that we have about asbestos but, again, I would emphasize the importance of dose. The assumption that doses, particularly in the para-occupational exposures, are low dose exposures, I do not think is a valid one on the basis of existing data, but the data are so pitifully small that one cannot either deny or assent; one can only say that much more information is necessary. Again, a short exposure is not necessarily a low dose exposure and a nonoccupational exposure may not be, either.

Let me close by saying one word on substitutes. Clearly the principles of biology that are applied to asbestos have to be applied to all substitutes, as I know in fact they are being applied, but it would be well to not repeat some of the omissions in our approach to the asbestos problem that have been taking place over the last half century in addressing these substitutes.

QUESTION (Mr. Kosner): I am from the NIEHS. We certainly owe a great debt to Dr. Kotin who is also the founding director of the National Institute of Environmental Health Sciences, the institute that I am with at the present time.

We do know that asbestos is associated with mesothelioma of the pleura and of the peritoneum. Unless we believe these substances act at a distance, we would have to believe that the particles must get to these sites in order to set up the conditions for the effect to occur.

I wonder if something also could be said about the stability of different types of fibers. For example, asbestos is quite different than fiberglass and some others in terms of its resilience and in terms of its strength and some other factors. It may be that some of these stay pretty much as they are, whereas other ones tend to break up and might be eliminated more rapidly. The way more sense is going to be made from this field in which so many different substances are being used is to find out these basic principles of uptake and release and integrity. We do know something about the importance of the length to the diameter.

Does Dr. Millette know something about the integrity of different types of fibers; rock wool versus fiberglass versus asbestos, et cetera?

ANSWER (Dr. Millette): In terms of ingestion there certainly is very little data on any material other than asbestos that has even been attempted. So, all you would have would be the casual findings of certain other types of fibers in other tissues, such as, gastrointestinal tissues, or finding, say, attapulgite fibers in the urine of a person receiving it in a high medical dose. So, very little really has been done with that.

REMARK (Dr. Rowe): That was a very good comment and question. I think that is an area that will have to be avidly pursued in the future.

MAN-MADE VITREOUS FIBERS AND HEALTH

by

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ABSTRACT

Asbestos fibers and manmade vitreous fibers differ in durability, fate and ability to cause disease. In man, asbestos is known to cause both malignant and non-malignant disease. In man, there is no credible evidence of malignant or chronic progressive non-malignant disease resulting from exposure to man-made vitreous fibers.

Airborne exposures of man-made vitreous fibers observed during manufacture, fabrication and installation are extremely low. With few exceptions, they are well below 1 fiber per milliliter.

No chronic progressive disease, either malignant or non-malignant, has been demonstrated to date by inhalation of man-made vitreous fibers in animal studies. Animal models demonstrate disease only as a result of non-physiologic exposure to long thin fiber by surgical implantation (mesothelioma) and by intratracheal injection (fibrosis).

GENERAL

Man-made vitreous fibers which include fibrous glass, rock and slag wool and ceramic fibers are products of 20th century technology. Mineral and slag wool were first manufactured in the early years of this century while fibrous glass was first produced in the 1930's and ceramic fiber roughly a decade later. These materials are used for thermal and accoustical insulation and reinforcement applications. Presently only a few of these applications overlap with asbestos usage and, therefore, man-made vitreous fiber cannot be considered truly a substitute for asbestos.

DIFFERENCES - ASBESTOS VS MAN-MADE VITREOUS FIBER

Vitreous fibers have come under suspicion as possible malignant or non-malignant disease producing materials largely because they are fibers. The dimensions of the smaller vitreous fibers overlap the dimensions of the larger asbestos fibers. The similarity ends there. It is useful to contrast man-made vitreous fibers and asbestos in terms of durability and fate.

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Durability

Fibers vary significantly in their durability or survival in living tissues. Gypsum disappears within hours after implantation, whereas some types of asbestos fibers can survive within tissues for the full life-span of exposed animals and humans. Between these two extremes there are varying intervals of durability for fibers of many types. Experimental studies[1] (e.g., Kuschner and Wright) report data suggesting that very fine man-made vitreous fibers have a marked tendency to disappear when compared to asbestos fiber.

Both _in vitro_ and _in vivo_ studies have shown that man-made vitreous fibers have a greater solubility than many asbestos fibers. (This should not be surprising when one considers the recognized variations in solubility among the several types of asbestos). Kuschner and Wright reported a fibrogenic response to very thin glass fibers (less than one micron in diameter), but, paradoxically, no biological effect of ultrathin fibers (less than 0.3 microns in diameter). After special efforts were made to ensure that this finding was not an artifact, the researchers were reasonably convinced that it was related with the disappearance of fibers.

Fiber Fate

Experimental studies in animal models and in humans have demonstrated that fibers can undergo cleavage, splitting, or fragmentation in the lungs.[1,2] This property varies among fibers, and, in fibrogenesis and cancer induction, it is of critical importance. Asbestos fibers are multifilamentous and split longitudinally, or along the long axis, into progressively thinner components that have been shown to be associated with chronic, progressive non-malignant and malignant disease in humans. Asbestos fibers fragment transversely with much less ease and frequency. In sharp contrast, man-made vitreous fibers are monofilamentous and do not split longitudinally into fibrils. Rather, they split and fragment only along the transverse axis, thereby becoming progressively shorter.[3] When one looks at the hilar lymph nodes draining the lungs of experimental animals, one can find fragments of vitreous fiber shorter than that to which the animals were exposed; thus some of the fibers may have been broken up in the lungs. With the long thin fiber concept, in which short fibers are recognized as being non-pathogenic, this property of man-made vitreous fibers moves them in the direction of less and less pathogenicity.

MAN-MADE VITREOUS FIBER PRODUCTS

Man-made vitreous fibers are produced in two broad categories: wools and textiles. Man-made vitreous fiber wool is used for example in commercial, industrial and residential insulation; acoustical ceiling panels; air-conditioning ducts; and mat products. The textile fibers or glass fiber yarns, roving and chopped strand mats have numerous applications including decorative and industrial fabrics; reinforcements for plastics, rubber and paper; electric insulation; filtration; and roofing materials.

FIBER DIMENSIONS AND RANGES

Man-made vitreous fiber manufacturing processes, especially the wool processes, do not produce fibers with absolutely uniform diameters. The diameters of the fibers in each product vary, hence the diameter of the majority of fibers in the product determines the "nominal diameter". If the actual diameters of man-made vitreous fibers produced by a particular process are plotted on a graph, the overwhelming majority of them will be "near" the nominal diameter. Generally, the further from the nominal fiber diameter one gets, the fewer fibers one will find - giving what often looks like a bell-shaped curve when the fiber diameters are plotted.

Although the vast majority of all man-made vitreous fibers products have a nominal diameter of 6 microns or greater, all products contain some fibers with diameters equal to or less than 1.5 microns. For over fifty years workers have been exposed to some fibers equal to or less than 1.5 microns in diameter contained in all products. Epidemiological studies of this worker population have failed to identify credible evidence of chronic, progressive non-malignant or malignant disease associated with this exposure.

Wool Fiber

Wool fibers are amorphous silicates made by blowing or spinning (fiberizing) a stream of molten vitreous material into fibers. Rock or slag wool fibers traditionally are made from furnace slag and/or limestone. In recent years, raw materials such as basalt, iron slag and phosphate slag have been used. Fibrous glass wool fibers are made from glass compositions that are carefully controlled formulations of silicon, aluminum, boron, calcium, sodium and other metal oxides.

Most products manufactured from the wool processes contain fibers that range in nominal diameter from approximately 6 to 9 microns. However, such products manufactured for over 50 years always have contained a small percentage of fibers with diameters equal to or less than 1.5 microns with lengths varying from 5 to 60 microns.

Textile Fibers

Textile fibrous glass products generally have larger nominal diameters than man-made vitreous wool fiber products. These textile fibers are drawn or extruded from holes in the base of the fiberizing equipment in a process which produces continuous fibers of infinite length, nominal diameters ranging from 6 to 25 microns and a very narrow range of diameter distribution. The majority of textile fibrous glass is used in reinforcement applications where a larger fiber diameter is desired for its superior reinforcing properties. For this reason, most of the textile fibrous glass produced are the larger diameter fibers. The finest diameter textile fiber, which has a nominal diameter of approximately 4 microns, is produced in relatively small quantities and is used for specialized fabric applications. Because of the controlled manufacturing process, textile fibrous glass contains only a minute amount of fiber with diameters less than or equal to 1.5 microns.

Fine Diameter Fibers

Fine diameter fibrous glass, which is produced by a flame-attenuated process, may include fibers that have a nominal diameter as low as 1 micron. These fibers have been produced on a commercial basis since the early 1940's in limited quantities.[4]

Very Fine Diameter Fibers

Very fine diameter fibrous glass, with a nominal diameter of less than 1 micron, is manufactured for certain highly specialized applications, such as aerospace insulation and sophisticated filtration and represents less than 1 percent of all production.

Ceramic Fibers

Ceramic fibers are wool-like products made from molten aluminum silicate. They have a nominal diameter of approximately 2 to 4 microns and a range of actual diameters from 0.5 to 12 microns, skewed towards the larger diameter fibers. These fibers are primarily used for high temperature applications including thermal blankets for industrial furnaces and vacuum cast parts for speciality products used in high temperatures.

BIOLOGICAL EFFECTS OF MAN-MADE VITREOUS FIBERS

Investigations into the health effects of man-made vitreous fibers can best be discussed under the headings of sampling studies, animal studies, *in vitro* studies and human studies. These fibers which have been in commercial use, for over 50 years, have failed to demonstrate any chronic, malignant or non-malignant pulmonary disease in man. In laboratory animals disease has been produced only when fibers were administered by an artificial route which bypassed physiologic defenses. The airborne concentrations of man-made vitreous fibers have consistently been demonstrated to be remarkably low, both in areas of manufacture as well as in areas of handling, application (with the exception of blowing applications) and use. Each of these points will be reviewed briefly, touching only on the most important aspects. No attempt will be made to cover every article which has been written on the subject.

I. Industrial Hygiene Studies

Several industrial hygiene studies have been reported.[5] The results of these studies are remarkably consistent. In general the airborne fiber concentration in ordinary wool fibrous glass manufacturing operations is 0.1 fiber or less per milliliter for airborne fibers less than 3.5 microns in diameter with about 25 percent of this material less than 1 micron in diameter. It is unusual to find airborne concentrations approaching 1 fiber per milliliter. While the lengths were variable, the majority of the fibers noted were longer than 10 microns. In the finer diameter fiber products (average diameter of 1 micron or less) the airborne concentration may exceed 1 fiber per milliliter in manufacturing and fabrication areas. Esmen[6] demonstrated that, generally, speaking, as the nominal diameter of the products increased the airborne concentration decreased. Similar findings were demonstrated in fabrication, packing and cutting areas of the plants. Industrial hygiene findings have shown that for any wool product, the average diameter or airborne fiber resulting from manufacture or fabrication operations will be smaller than the average diameter of the product. As an example, the average diameter of building insulation runs from approximately 6 to 9 microns while the average diameter of airborne fiber resulting from the manufacture or fabrication of this material will be in a range of approximately 1 of 2 microns. It can be generally stated that the light microscopic counts will be approximately equal to the electron microscopic counts for ordinary type fibrous glass. This does not hold true for the special finer fiber products (average product diameter of 1 micron or less) where the electron microscopic count may be greater than the count by light microscopy.

Esmen,[7] in a recent study for the Thermal Insulation Manufacturers Association to determine airborne fiber concentrations in operations utilizing man-made vitreous fibers, has demonstrated that during a field installation of thermal insulation materials including ordinary building insulation, acoustical ceiling and fibrous glass duct insulation, the average airborne concentration of fibers was well below 1 fiber per ml with the exception that during the application of blowing wool into closed attic spaces the time-weighted average airborne concentration ranged up to 6 fibers per ml.

In this same study, Esmen reported industrial hygiene sampling of aircraft insulation fabrication where the material was being sewed, cut and cemented. This material is high efficiency, specialized insulation which is 1 micron in nominal diameter. The airborne concentration was generally below 1 fiber per ml.

II. Animal Studies Involving Man-Made Vitreous Fibers

Although animal studies have been undertaken since the 1930's, the most pertinent studies include Gross'[8] inhalation study in 1970 where he exposed rats and hamsters to 100 mg per cubic meter of air of fibrous glass that had a nominal diameter of approximately 1 micron and a diameter in the chamber air of 0.5 microns. Seventy percent of the airborne material was reported to be fibrous. The fiber lengths were between 5 and 20 microns. These studies demonstrated no appreciable alteration of lung architecture, minimal pleural change, no significant fibrosis and no tumor development in animals exposed for 24 months and domiciled for the remainder of their lifetime. Other inhalation studies by Botham and Holt,[9] Timbrell,[10] Harris,[11] Harris and Fraser,[12] Lippmann[13] and Brain[14] utilizing fibrous glass, designed to look at such things as deposition and clearance as well as pathological changes, demonstrated non-specific pulmonary responses with a relatively wide variation but no tumor formation or significant fibrosis.

Wagner,[15] in England, has recently reported that his inhalation experiments utilizing a very fine diameter fibrous glass with a mean diameter of 0.3 microns and rock wool with a mean diameter of 0.8 microns, have failed to demonstrate fibrosis with the only reaction being a minimal non-specific cellular dust response. This study is still on-going and must await completion for final evaluation.

A number of intratracheal injection studies have been carried out over the years beginning in the late 1930's. The more significant studies were those carried out by Gross,[8] and by Wright and Kuschner.[1] These studies demonstrated a wide variety of cellular response with no significant chronic pulmonary effects, with the exception of the Wright-Kuschner study. Wright and Kuschner demonstrated a peribronchiolar fibrosis in guinea pigs intratracheally injected with long thin fibrous glass. This response was qualitatively similar to a response to chrysotile asbestos but quantitatively much less. The authors commented that this information could not be directly extrapolated to man because the method or administration bypassed all natural respiratory defense mechanisms. The study did show, however, that massive doses artificially placed at the target site caused fibrosis if the fibers were significantly long and thin (less than 1.5 microns in diameter and greater than 10 microns in length). The authors felt that additional inhalation studies using long, thin fibers were indicated. Such studies are now being conducted.

Quite significantly, malignant tumors have not been produced by intratracheal injection of man-made vitreous fibers with dimensions known to produce them by surgical implantation. The Wright-Kuschner intratracheally injected animals were sacrificed after 2 years and Gross[8] animals, similarly exposed, were permitted to live out their lives.

Intracavitary implantation in animals of man-made vitreous fibers as well as a variety of other fibrous materials has been carried out by a number of investigators[16,17,18,19,20] in this country and abroad. Mesotheliomas have been produced at the sites of surgical implantation and injection into the pleural and peritoneal cavities of animals using high doses of many types of materials. The materials included specially prepared long, thin fibrous glass fibers (fibers less than 1.5 microns in diameter and greater than 8 to 10 microns long). The implantation of the type of fibrous glass commonly used as insulation material however, which does contain some fibers less than 1.5 microns in diameter, failed to elicit mesothelioma production.[21] Stanton,[16] who performed the major surgical implantation study, noted that "Direct application of our results (the implantation study findings) to the problems in man would be unwise because of the method of application and the high doses used are remote from the usual exposure of man to fibers ..."

III. In Vitro Effects

A number of studies have been conducted *in vitro*. The reported results have been mixed.[22,23] The question arises for the need to test man-made vitreous fibers in an *in vitro* system since it has been demonstrated *in vivo* that long thin fibers, when implanted into the abdominal and chest cavities, do cause mesotheliomas. It is suggested that the human health effects of man-made vitreous fibers are best evaluated through further animal studies and by epidemiology. Such studies are currently underway. The progress of one of these studies is being reported here at this symposium.

IV. Cross Sectional Studies of Currently Exposed Workers

Cross sectional studies have been carried out since 1942 on man-made vitreous fiber exposed workers. These studies have been largely fibrous glass exposed workers. Several of these studies have been carried out at the same plant. That facility is the oldest continuously producing fibrous glass plant in the United States. This plant has been repeatedly studied by Wright, by deTreville, by Nasr and by Utidjian utilizing cross sectional morbidity techniques. Wright[24] studied 1389 fibrous glass workers who were employed from 10 to 25 years. The study demonstrated no unusual pattern on chest roentgenograms that could be attributed to fibrous glass exposure. Utidjian[25] reported the evaluation of 232 randomly selected workers from this same plant. The study demonstrated no major effect on lung function after long term exposure. deTreville,[26] using a subsample of Utidjian's workers, which included 30 long term fibrous glass workers, 15 with minimal and 15 with heavy subjective exposure, evaluated the subjects for cardiac and pulmonary status including blood gas studies. He noted no significant differences between the two groups of exposed workers. Nasr,[27] examining 2028 chest x-rays of fibrous glass workers in this plant, observed no difference in the incidence of abnormalities between the exposed factory workers and non-exposed office workers and no radiographic effects resulting from fibrous glass exposure. Hill,[28] in evaluating 70 workers with occupational exposure to fibrous glass with an average exposure time of approximately 20 years, found that chest x-rays and pulmonary function studies of the workers were not significantly different from an unexposed group matched for age, height and weight.

Gross,[29] comparing the lungs of 20 insulation fibrous glass manufacturing workers whose periods of exposure ranged from 16 to 32 years to the lungs of 26 urban dwellers with no history of fibrous glass exposure in the workplace, noted no significant difference in lung fiber content or fiber dimensions between the groups. He further concluded that long term exposure to the dust of fibrous glass caused no gross or microscopic pulmonary damage.

Upper respiratory irritation has been reported by several authors.[30,31,32,33,34] It is often found following unusually dusty conditions, particularly in situations involving the dry method of tearing-out of installed man-made vitreous fiber materials. After the initial irritation has passed there is complete resolution of the condition.

Transitory skin irritation by man-made vitreous fibers in some workers is known to occur. This has been reported by many authors[35,36,37,38,39] over the years. All authors agree that it is a mild, mechanical irritation which lessens in intensity after several days of continuous occupational exposure. The ability to cause irritation is related to the diameter of the fiber. The larger the diameter of the fiber, the more likely the material is to cause irritation. There is no evidence that the skin irritation is other than a transitory mechanical one. There is no allergic component.

V. Mortality Studies Involving Man-Made Vitreous Fibers

The above mentioned cross sectional morbidity studies are useful in identifying a lack of non-malignant "dust related" disease. However, such studies could fail to demonstrate disease which had a long latent period. For this reason, epidemiological mortality studies of workers with long exposure to airborne fibrous glass in manufacturing operations have been done. Such studies have been carried out and are currently in progress. Among these studies is Bayliss'[40,41,42] work which included 1448 workers occupationally exposed to fibrous glass. This study found no significant malignant respiratory disease, 20 or more years after onset of fibrous glass exposure. The author did note 19 non-malignant respiratory disease deaths, excluding pneumonia and influenza, compared to an expected 10 deaths. However, more than half of the decedents had previous exposure in dusty environments, including nine in a foundry, one in a silica batching operation and one with an exposure in coal mining. Further, smoking histories were not available. The plant population used in the Bayliss study was the same as used on different occasions by Wright, Nasr, Utidjian and deTreville. Therefore, it seems likely in light of the work histories involved that any significant non-malignant respiratory disease would have been discovered by these studies. The proposition that susceptibles would select themselves out of the working population is not realistic. A case in point is the all too common findings of asbestosis--a legacy of past exposure--being identified in current asbestos exposed workers.

The Bayliss case control study, which attempted to study malignant and non-malignant disease in manufacturing workers exposed to finer diameter fiber (1 micron average diameter) was inadequately designed and analyzed, and incorrectly classified some of the workers as having contact with finer fiber. The results were reported as borderline statistically significant.

Recently Enterline[43] reported his findings on the first eight plants in a study that will encompass 17 man-made vitreous fiber manufacturing facilities. This study has not considered smoking histories, which were unavailable. The initial study group of eight plants included 7049 workers, 6023 workers from five fibrous glass manufacturing plants and 1026 workers from three rock wool or slag wool plants. Compared to expected deaths from all causes in the United States, the initial report indicated 7 percent fewer deaths among the cohort. Twelve percent fewer deaths than expected were attributed to respiratory cancer. Thirteen percent fewer deaths than expected were attributed to malignant disease of the digestive organs or peritoneum. Five percent more deaths than expected were attributed to non-malignant respiratory disease excluding influenza and pneumonia. None of these deviations is statistically significant. An important point is that while the Enterline study noted fairly wide variations in mortality ratios between plants, each with a relatively small number of employees, the mortality ratios of the plants as a group were close to 100, which is the expected statistical norm. The author has stated he does not believe there is any evidence in his study of an excess in malignancies due to man-made vitreous fiber in the plants he has studied to date.[44]

Another recent study by Robinson[45] reported on a cohort of 595 workers from just one of the rock wool plants included in the Enterline study. The resulting standard mortality ratio for all causes of death was lower than the adjusted United States population. The author suggested that lung cancer, non-malignant respiratory disease and digestive cancer showed a progressive rise related to time from first exposure. This was evident in workers exposed for more than 30 years. However, there were no statistically significant excesses of malignant or non-malignant respiratory disease or digestive cancer for the entire cohort. The numbers were extremely small and a careful examination of the data does not demonstrate any consistent pattern for malignant respiratory disease, non-malignant respiratory disease or digestive cancer. The healthy worker effect and the fact that smoking histories were not considered also must be kept in mind when interpreting the data. The Enterline study, encompassing a much larger group of workers, is more pertinent and indicates no significant excess for these causes of death.

Very recently a report[46] has been received on a retrospective cohort study of 6536 fibrous glass production workers--all from one company but in multiple plants--who worked 10 or more years with some portion of that employment between 1968 and 1977. A special component of this investigation was an analysis of a long term cohort of 1240 individuals with 20 or more years of employment and 30 or more years latency.

Analysis of the data reveals that for any cause of death there was no marked excess or statistically significant increase in mortality. In fact, the pattern of mortality for fibrous glass production workers appears considerably lower than comparable U.S. patterns. Long-term workers enjoyed an even more favorable mortality experience than those employed for shorter periods.

SUMMARY

1. Asbestos fibers and man-made vitreous fibers differ in durability, fate and ability to cause disease. In man, asbestos is known to cause both malignant and non-malignant disease. In man, there is no credible evidence of malignant or chronic progressive non-malignant disease resulting from exposure to man-made vitreous fibers.

2. Airborne exposures of man-made vitreous fibers observed during manufacture, fabrication and installation are extremely low, with few exceptions, well below 1 fiber per milliliter.

3. No chronic progressive disease, either malignant or non-malignant, has been demonstrated to date by inhalation of man-made vitreous fibers in animal studies. Animal models demonstrate disease only as a result of unnatural exposure to long thin fiber (less than 1.5 microns in diameter and greater than 10 microns long) by surgical implantation (mesothelioma) and by intratracheal injection (fibrosis).

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DISCUSSION ON MAN-MADE VITREOUS FIBERS

QUESTION (Dr. Cooper): You did not mention mesothelioma in your epidemiologic studies and I am sure no mesothelioma occured in any of these populations. I would have thought the absence of them would have been noteworthy also.

ANSWER (Dr. Konzen): The data made no mention of mesothelioma.

THE TRANSLOCATION AND FATE OF SIZED MAN-MADE MINERAL FIBERS FOLLOWING EXPOSURE BY INTRATRACHEAL INSTILLATION IN RATS

by

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ABSTRACT

A number of studies have suggested that both the length and diameter of glass fibers are important parameters in determining their deposition and translocation in the lung and in the subsequent pathological response by the lung. However, the fibers used in these previous studies had broad size distributions and were often administered in a highly artificial manner. To better characterize the biological response to glass fibers, a study is being conducted to determine the translocation and ultimate fate of fibers of defined sizes after introduction into the respiratory tract of rats by both instillation and inhalation. The fibers have geometric mean diameters of 1.5 μm ($\sigma g = 1.11$) and lengths of either 5μm ($\sigma g = 1.49$) or 60 μm ($\sigma g = 3.76$).

Serial sacrifices following intratracheal instillation of either 2 mg or 20 mg doses have shown differences in the response to the two sizes of fibers. The short fibers are found primarily within mononuclear phagocytes in both the lung and regional lymph nodes. The majority of long fibers, however, cannot be totally engulfed by macrophages, nor are they cleared to the regional lymph nodes, although smaller fragments accompanying the long fibers may be so cleared. The long fibers produce a striking foreign body reaction in the lung, particularly when impacted in the bronchi.

A "trachea only" inhalation method was used to expose rats to approximately 500 fibers/cc for one hour, resulting in the deposition of 30,000 to 50,000 fibers in the lungs of each rat. Serial sacrifices at intervals similar to those in the instillation study will permit comparison of the biological response following these two methods of administration.

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*Presented by David M. Bernstein, Ph.D.

INTRODUCTION

The length and diameter of glass fibers determine not only their deposition in the lung [1,2] through inhalation but are also thought to be important factors in fiber translocation and subsequent pathological response.[3] Stanton and Wrench[4] demonstrated that when placed directly into the pleural cavity of rats, glass fibers are associated with the development of mesothelioma. It remains unclear whether glass fibers actually reach the pleural cavity when administered in a less artificial manner through the tracheobronchial tree. In the past, resolving the relationship of fiber size to these effects has been compounded by the difficulty in separating different lengths of fibers of the same diameter. Using fibers manufactured to specified size distributions, this study has examined the deposition, translocation, and fate of glass fibers after introduction into the respiratory tract of rats.

Three routes of exposure were initially considered; intratracheal instillation of aqueous suspension, nose only inhalation exposure, and insufflation of a very thick air suspension of fibers. The intratracheal instillation provided a means of administering large quantities of fibers into the lung with relative ease. Rats are obligatory nose breathers and when inhaled through the nose the majority of the long fibers used in this study were found to deposit in the tortuous nasopharyngeal region of the rat. Hence, a trachea only inhalation exposure method was developed to expose animals to fiber aerosols. With the successful development of the trachea only inhalation methodology, insufflation of very thick air suspensions of fibers was not pursued further.

This report reviews the methods and techniques developed for exposure by intratracheal instillation, presents the glass fiber clearance data, and summarizes the histological findings through six months post exposure.

MATERIALS AND METHODS

The fibers were manufactured to either 1.5 x 5μm or 1.5 x 60 μm in size[5]. The length distribution of each group of fibers is shown in Figure 1 with the short fibers having a geometric mean length of 5.1 μm (SD = 1.49) and the long fibers a geometric mean length of 54 μm (SD = 3.76). Scanning electron micrographs of the fibers are shown in Figures 2 and 3. The fibers were neutron activated and ZN^{65} determined to be the best tracer nuclide to allow quantification of deposition and clearance of the fibers in vivo.[5]

Animals

These studies were conducted with male Fisher 344 rats purchased from Charles River. The exposures were begun when the animals were approximately 15 weeks old. They were housed in wire cages, allowed food and water ad libitum, and maintained on a 12 hr light cycle at 22 ± 2°C, 50 percent relative humidity.

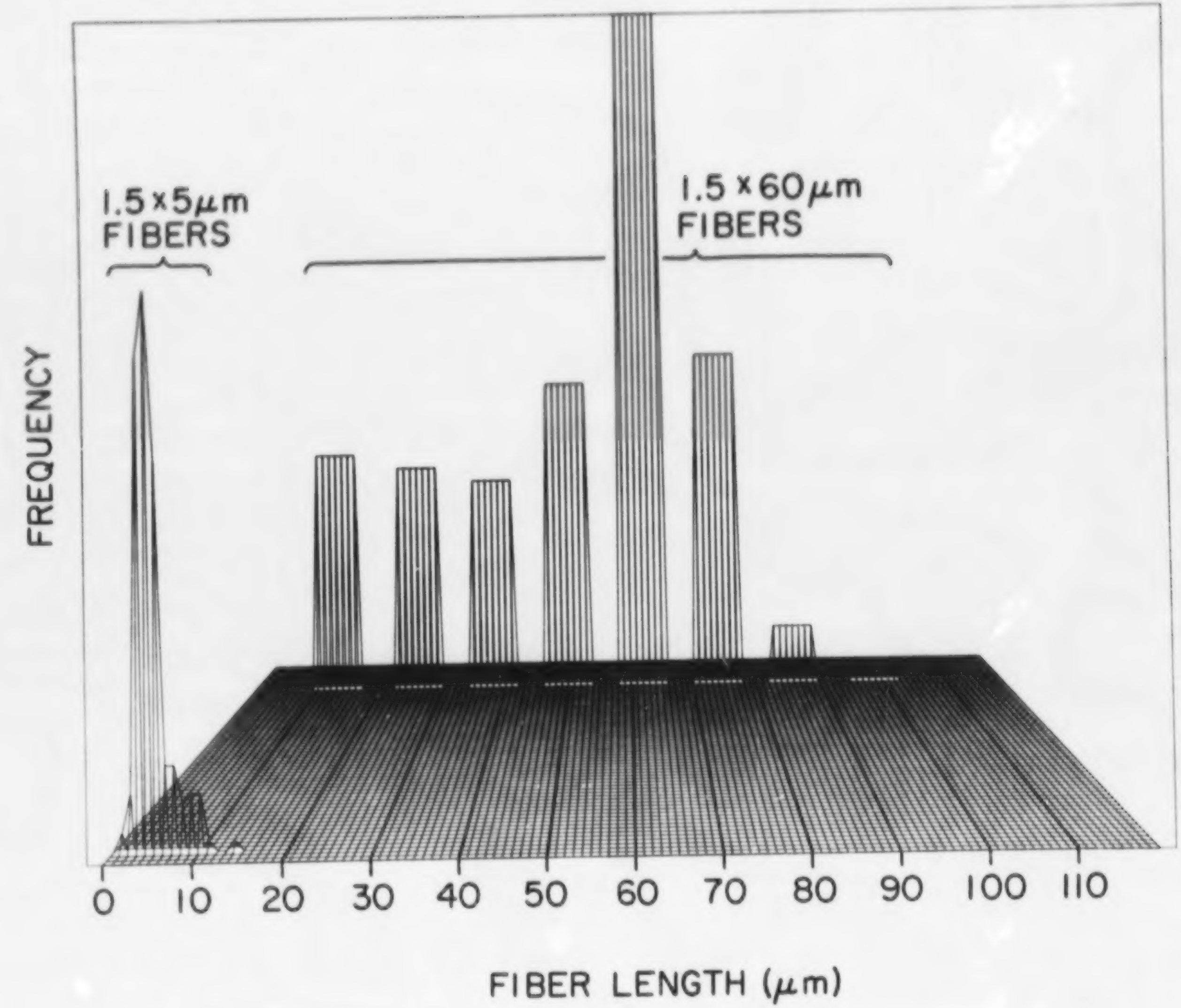

Figure 1. Length distribution of each group of fibers.

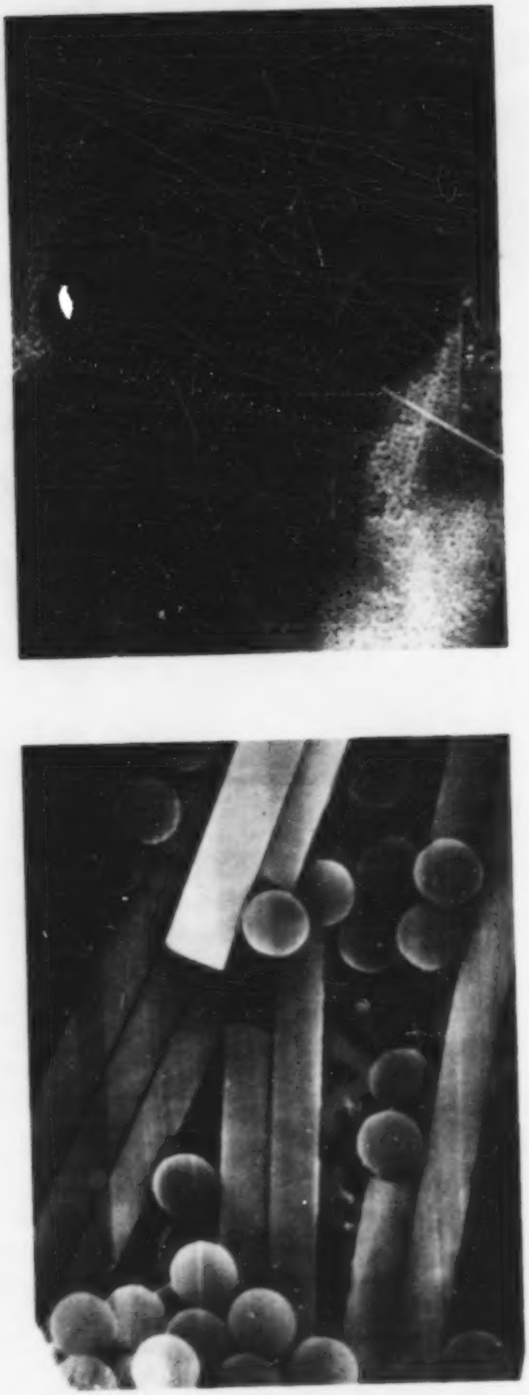

Figure 2.

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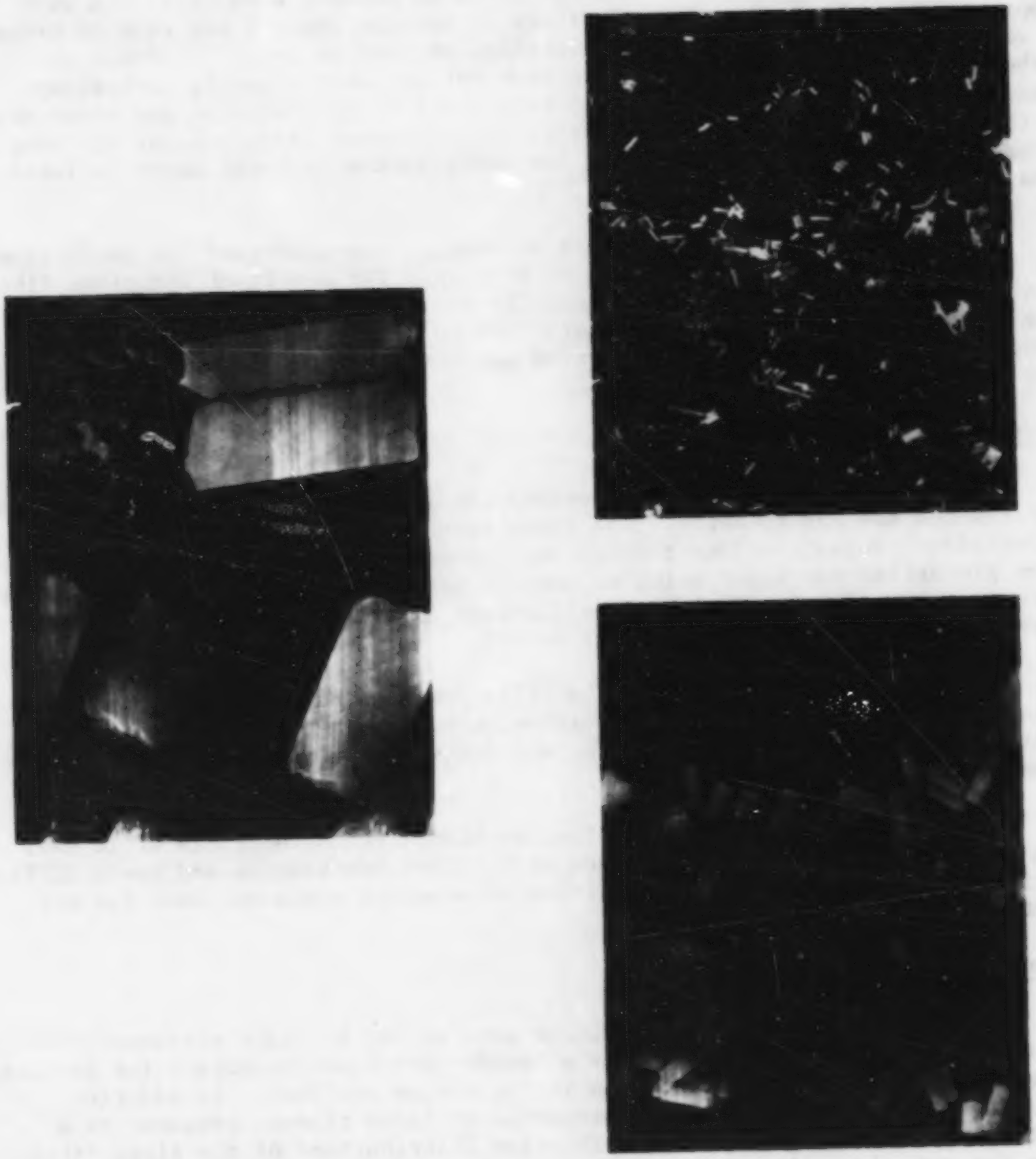

Figure 3.

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Intratracheal Instillation

The techniques for intratracheal instillation of the glass fibers have been described earlier[5]. Thirty rats per group were instilled with either 1.5 x 60 μm (Group 1) or 1.5 x 5 μm fibers (Groups 2 and 3) that were tagged by activation as outlined in Table 1. Rats in Group 2 were instilled with approximately the same number of fibers as rats in Group 1 and rats in Group 3 were given the same weight of fiberglass as rats in Group 1. Since the fiber concentration administered to each rat was determined by radioassay immediately after exposure, only 15 rats could be instilled on any given day. With this limitation and the necessity to radioassay the groups at the same time intervals following exposure, the instillation protocol shown in Table 1 was developed.

In addition, 50 rats/group were exposed to non-activated (or cold) fibers to insure that potential long term effects were the result of the glass fibers and not the small amount of radioactivity present. This number of animals was chosen from statistical considerations to permit detection of a two tumor difference between the activated and non-activated exposure groups at the end of two years.

Necropsy

The rats were sacrificed by pentabarbital anesthesia with exsanguination through the descending aorta. The lungs were then perfused in situ with heparinized isotonic saline through the pulmonary artery, removed, and inflated with glutaraldehyde vapor using an endotracheal tube (at a pressure of 20 cm water); and then infused with glutaraldehyde fixative through the pulmonary vasculature (at a pressure of 20 cm water).

After the lungs were fixed, the hilar lymph nodes, thymus, and adipose tissue were dissected away. In addition, the diaphragm, gastrointestinal tract, liver, spleen, kidney, brain, and femur were removed for histological examination.

Tissues were embedded in parafin, sectioned (at a thickness of 10 μm), mounted on glass slides, and stained with either hemotoxylin and eosin (H&E), reticulum, or trichrome stains. Histoclad mounting media was used for all sections.

Microscopy

The standard histological sections were viewed by light microscopy for histopathological evaluation and by a pseudo-dark field technique for evaluation of glass fiber numbers and location in the tissue sections. In addition, scanning electron microscopy was performed on fixed tissues prepared by a critical point drying technique. The size distributions of the glass fibers were determined by microscopic measurement with the aid of a Zeiss MOP-3 image analyzer.

TABLE 1. FIBER GLASS INSTILLATION SCHEDULE*

Exposure Group	Fiber Size and Dose	Number of Rats Instilled	Date of Instillation
Group I	1.5 × 60 μm	14	2/26/79
	20 mg	16	2/28/79
Group II	1.5 × 5 μm	14	3/26/79
	2 mg	17	3/28/79
Group III	1.5 × 5 μm	15	3/12/79
	20 mg	15	3/14/79
Group IV	Saline	15	4/9/79
	Control	15	4/11/79

*The instillation schedule was staggered as shown to permit radioassay of each rat following exposure.

TABLE 2. FIBER CONCENTRATION

Exposure Group	N	Mean	(Standard Deviation)
20 mg 1.5 × 60 μm	21	0.15	(0.04)
2 mg 1.5 × 5 μm	24	0.09	(0.04)
20 mg 1.5 × 5 μm	22	0.18	(0.02)

Note: Fraction Remaining at ~300 days after Exposure.

RESULTS

Animal Weights

Rats were weighed in each group at equal intervals after exposure. Since the time of exposure was offset as shown in Table 1 and the rats were all of the same age when received, the weight curves were shifted reflecting this temporal offset in exposure. The growth curves for each group were not significantly different as determined by an F test on the slopes and shown by the parallel curves in Figure 4.

Glass Fiber Clearance

The clearance of glass fibers from the rats was determined by in vivo radioassay of each animal. It is important to note, however, that this technique only accounts for whole body clearance of fibers and is not sensitive to translocation of fibers within the rat.

The clearance curves for each of the three exposure groups through ~300 days are shown in Figures 5, 6, and 7. The low dose short fiber clearance is significantly different, $P < 0.01$, from either the long or short high dose group (as determined by analysis of covariance). This is reflected in the percent remaining at ~300 days as shown in Table 2. If the data is evaluated by a three component exponential model in terms of short, intermediate, and long term phases of clearance (Table 3), significant differences ($P \sim 0.01$) are noted in the short and intermediate phases of the two high dose groups.

Scanning Electron Micrographs

To examine the pulmonary response to the two types of fibers by electron microscopy, rats instilled with 20 mg of either long or short fibers were sacrificed two weeks after exposure. The lungs of rats exposed to long fibers are shown in Figures 8 and 9. Macrophages attempting to phagocytize the long fibers are readily noted (Figure 8). In addition, other areas are seen with clumps of fibers present associated with a nodular densely aggregated cellular response (Figure 9).

This is in contrast with the response to the short fibers seen in Figures 10 and 11. These short fibers are found in large numbers in macrophages and for the most part are completely engulfed by these cells. Some fibers are seen free in airspaces (Figure 11). The nodular aggregates noted with the long fibers are not evident.

Histological Results

The histological results reported here are from the first serial sacrifice at six months post exposure involving four animals/group. In addition, a few animals died under anesthesia for the radioassay procedure. These animals were sacrificed as described above and the histological results presented as well.

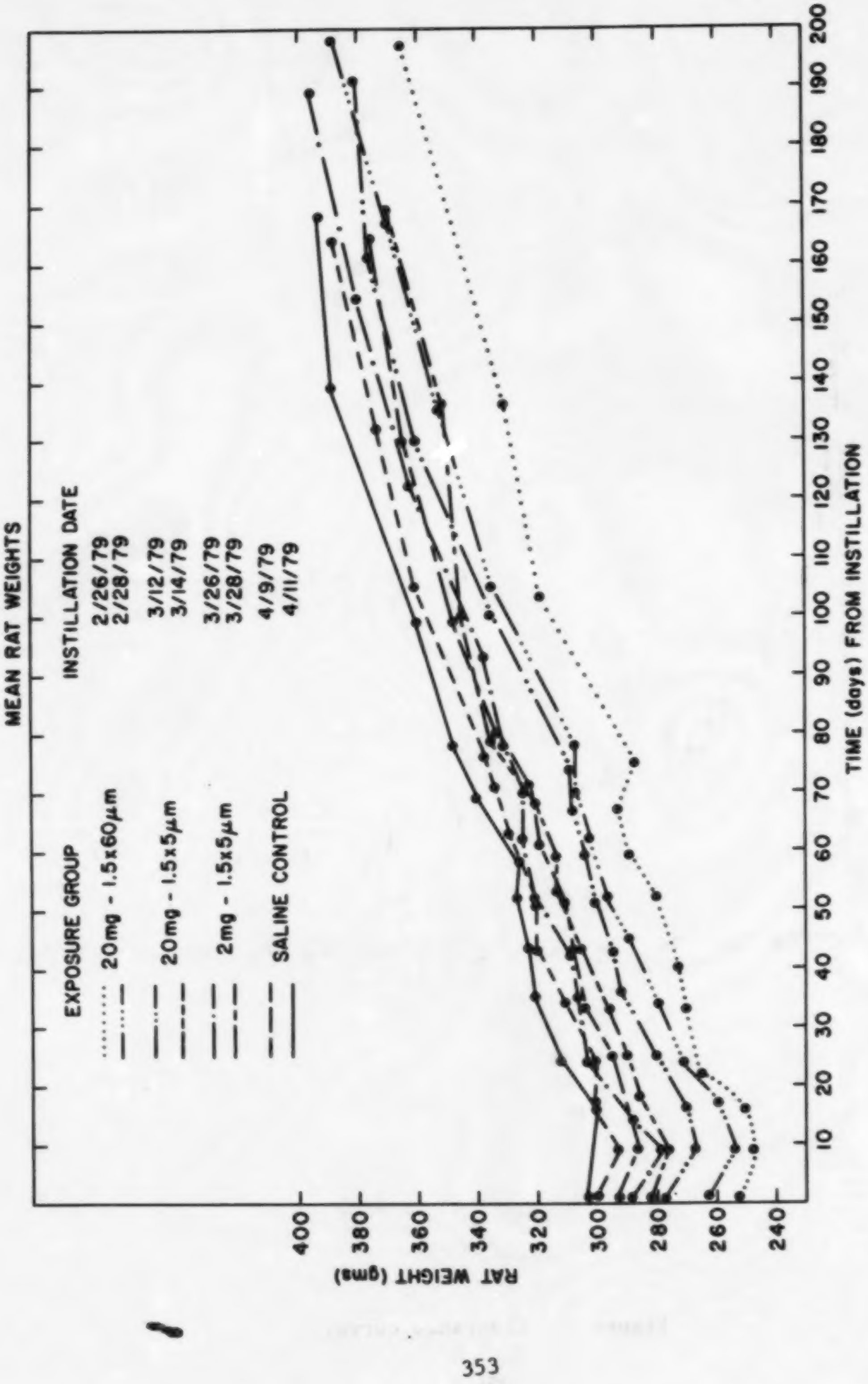
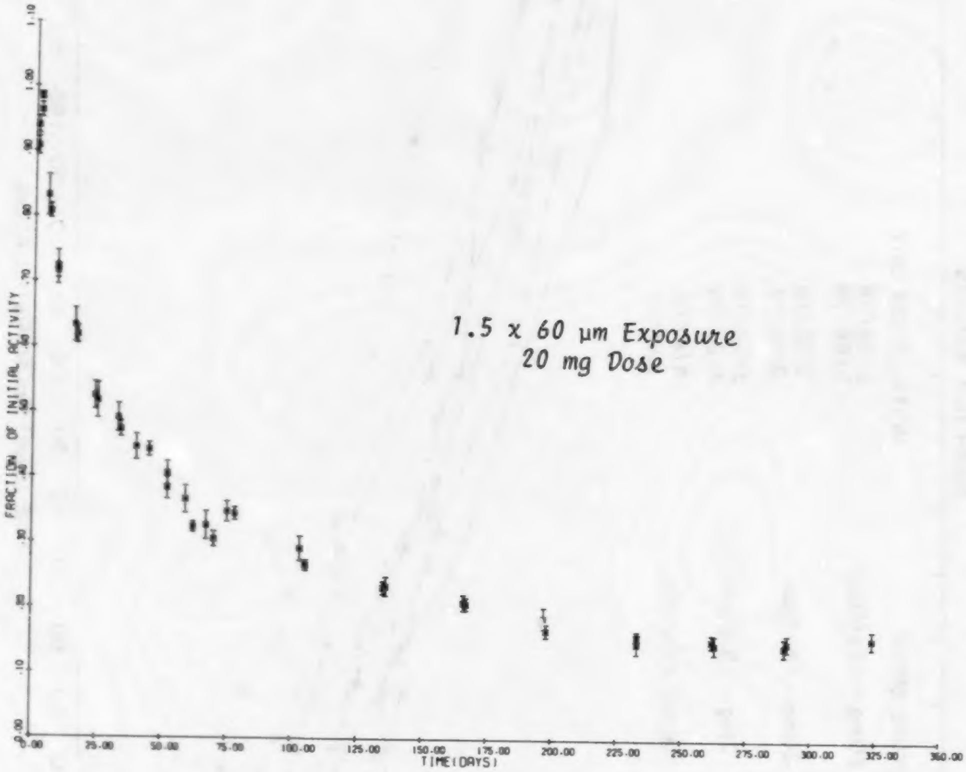


Figure 4. Growth curves.



1.5 x 60 μm Exposure
20 mg Dose

Figure 5. Clearance curve.

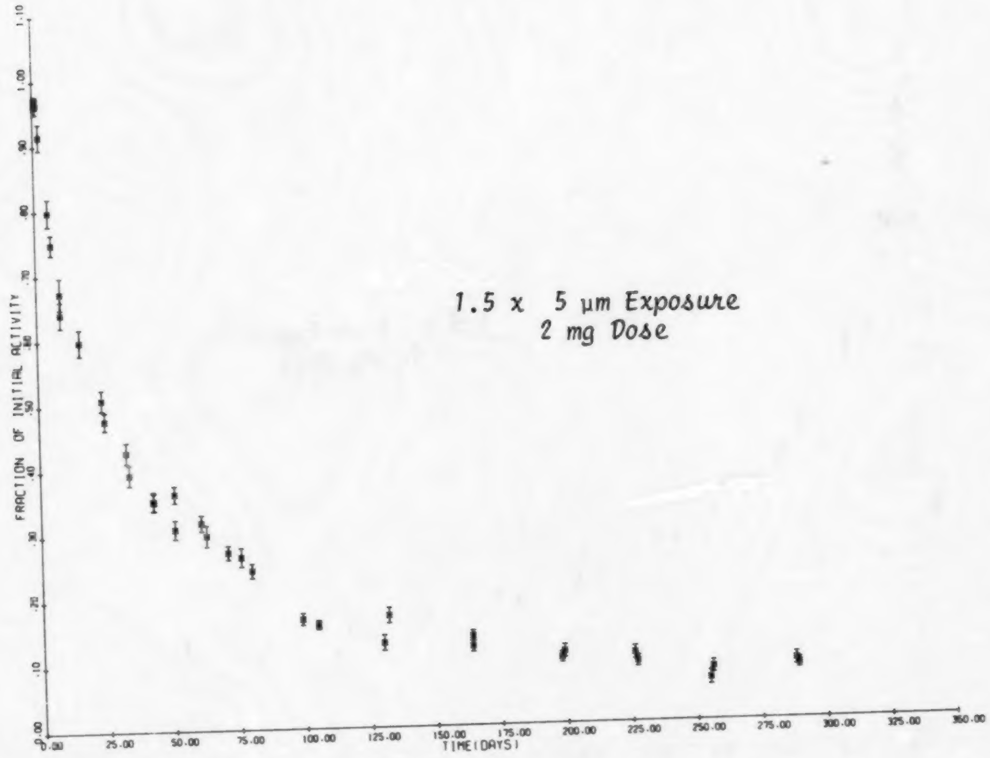


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Figure 6. Clearance curve.

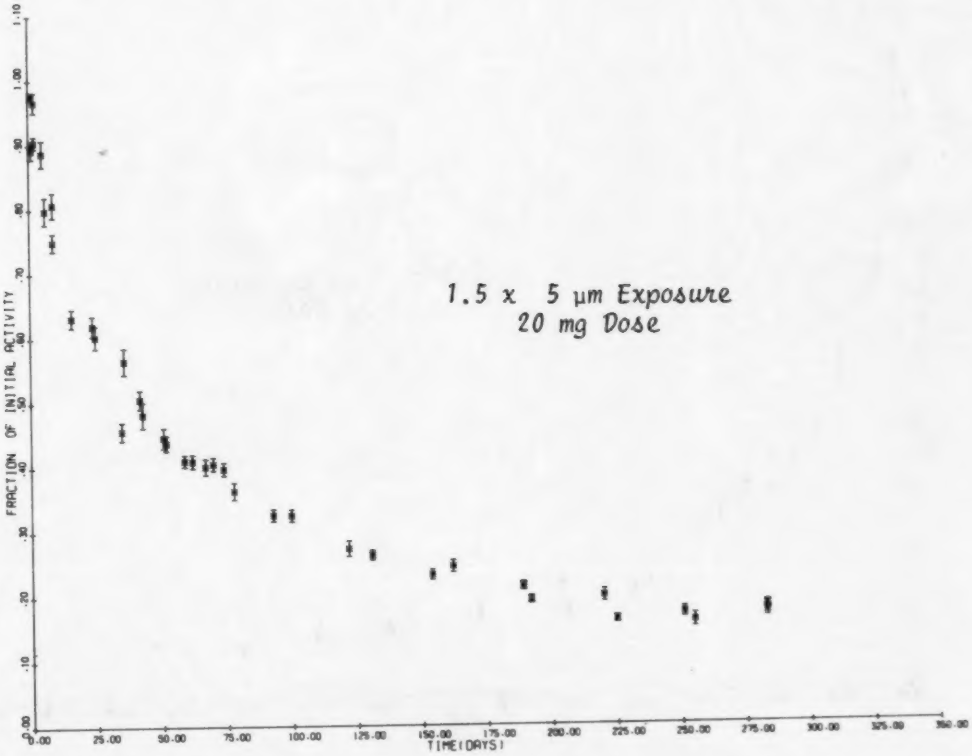

Figure 7. Clearance curve.

TABLE 3. FIBER GLASS CLEARANCE
THREE COMPONENT EXPONENTIAL MODEL

Exposure Group	Clearance half times (days)		
	1-10 days	11-60 days	61-300 days
20 mg 1.5 × 60 μm	20	58	173*
2 mg 1.5 × 5 μm	14	43	115
20 mg 1.5 × 5 μm	29	63	173*

*Not significantly different. All other half times are significantly different from one another ($P \leq 0.01$).

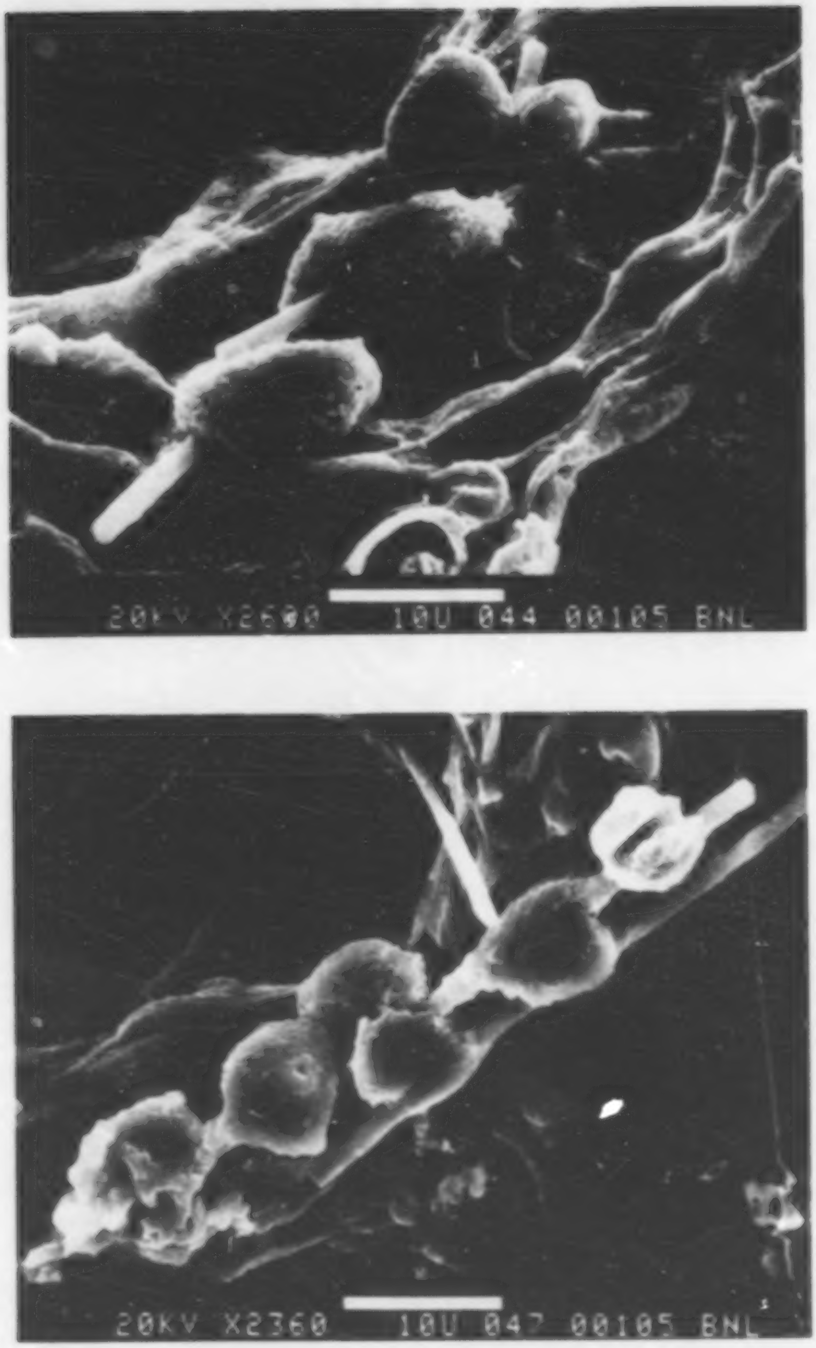
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Figure 8.

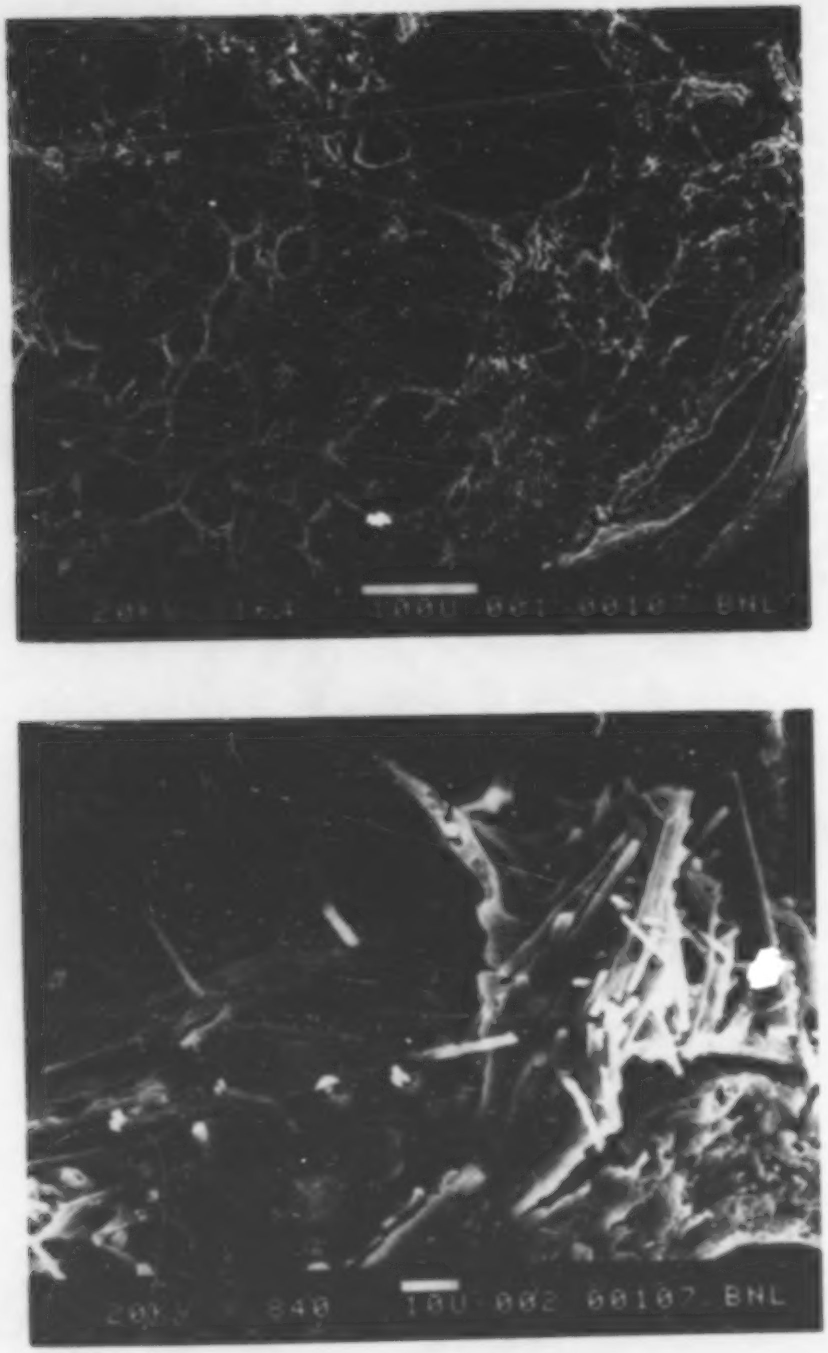
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Figure 9.

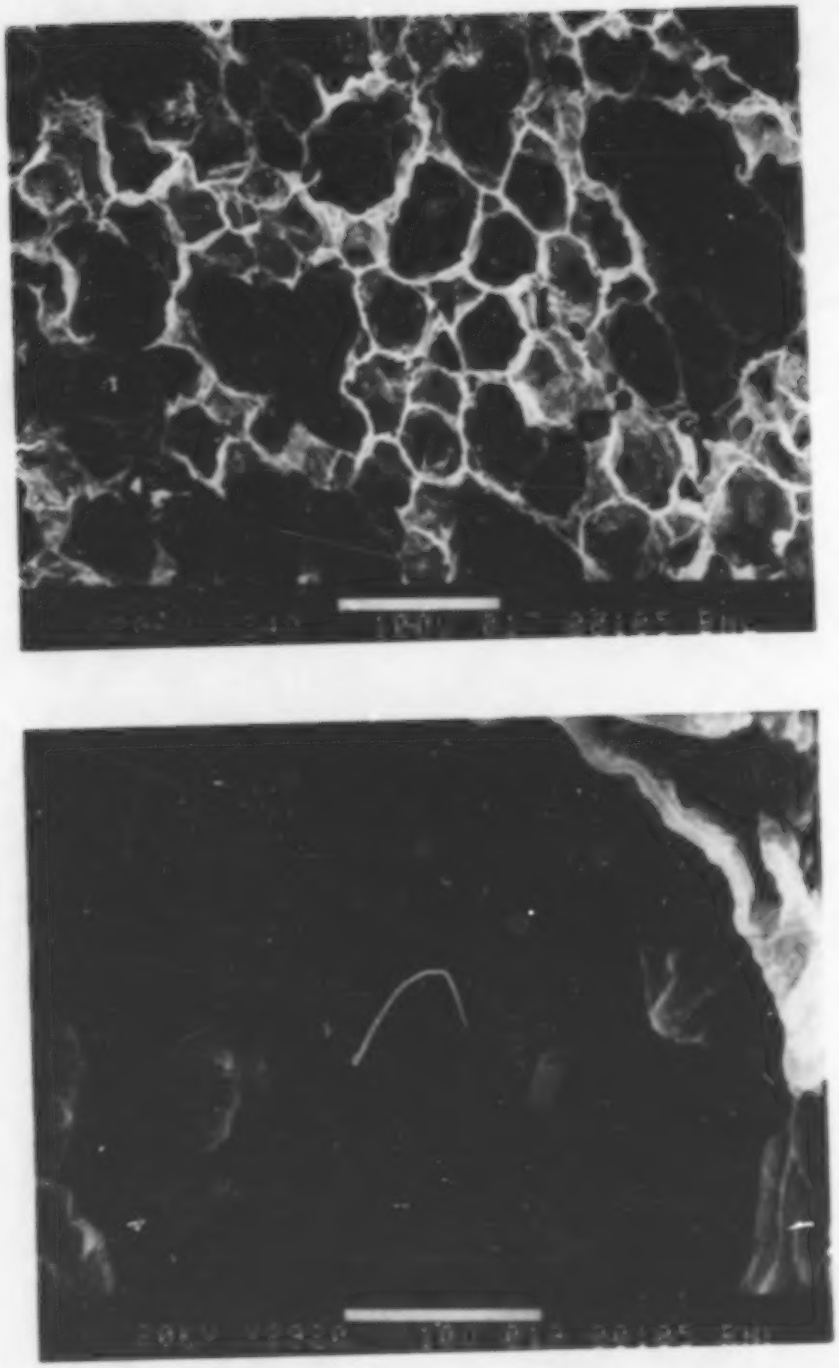

Figure 10.

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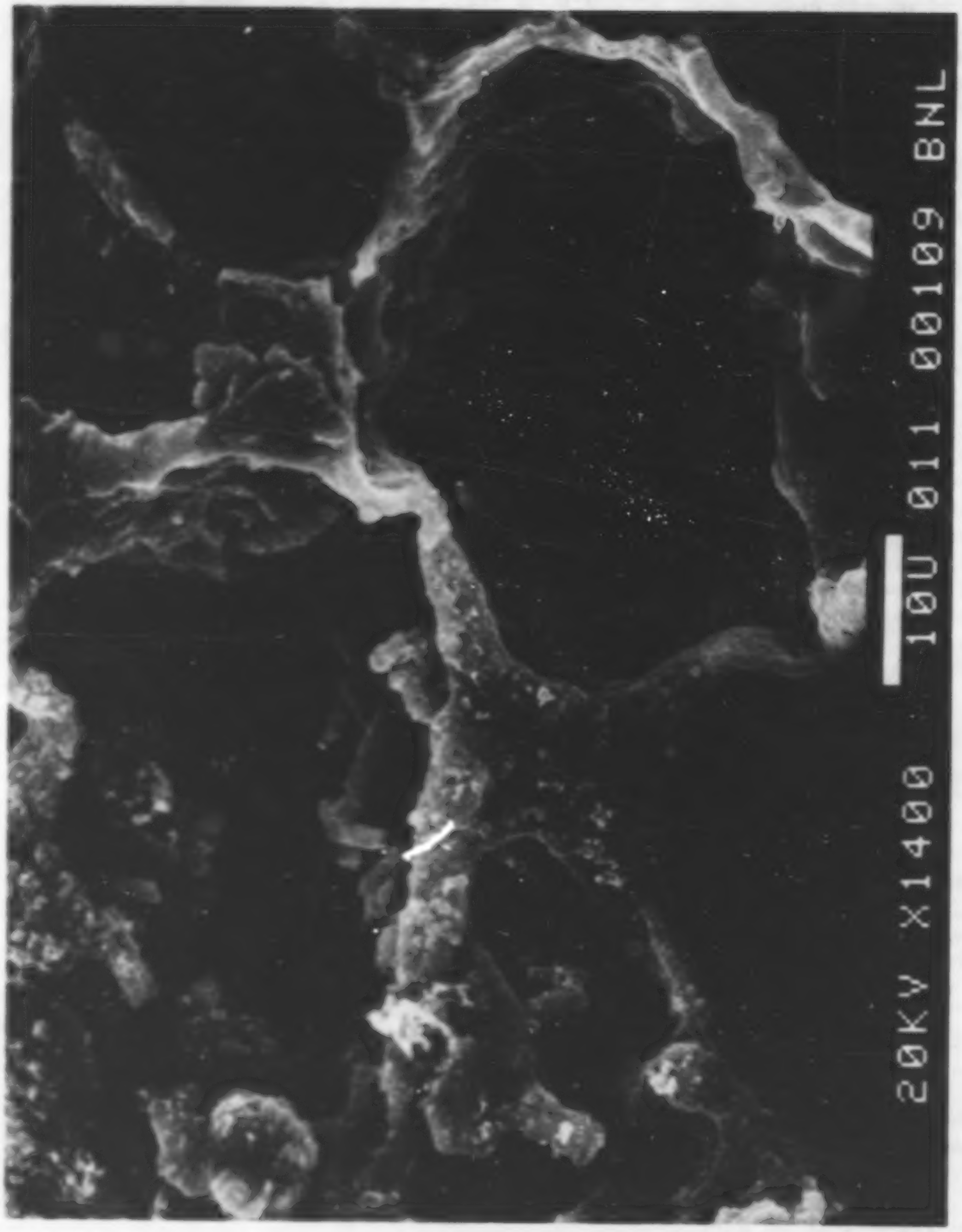
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Figure 11.

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To illustrate the numbers and locations of fibers and their associations with the histological observations, photographs for many of the light field H&E stained sections are accompanied with a dark field image of the same field which highlights the fibers. It should also be noted that with 10 μm sections of the lung, it is likely that a 60 μm fiber would be cut in the sectioning process. This, together with the fibers being somewhat randomly orientated in the lung may give the appearance that the long fibers are somewhat shorter than 60 μm.

1.5 x 60 μm Fibers, 20 mg Exposure

At 4 days post-exposure a notable cellular response in association with large numbers of fibers was observed (Figure 12). The initial stages of granuloma formation were evident by 10 days (Figure 13), however, no giant cells were observed. Many fibers were seen either free in the alveolar space or in association with macrophages. By 40 days (Figure 14) the granulomas were more defined and giant cells within these granulomata were easily seen.

Microscopic examination of the 6-month sacrifice of four rats/group showed that the lungs contained numerous granulomata which were well developed, containing epitheloid cells, giant cells, and large numbers of fibers (Figure 15). These granulomata were often peribronchiolar in orientation (Figure 16); fairly uniformly distributed throughout the sections, and sharply demarcated at their margins. Moderate numbers of fibers occurred singly or in small groups outside the granulomata (Figure 17) often in the interstitum, however, relatively few fibers were seen within the alveolar spaces. Hemosiderin was present in association with the fibers. No 60 μm fibers were seen in the lymph nodes although occasional smaller fibers or fragments or larger ones were present (Figure 18).

1.5 x 5 μm Fibers, 2 mg Dose

No animals in this group died prior to the 6-month sacrifice.

At 6 months, animals exposed to 2 mg of the short fibers revealed a generally heterogenous distribution of the residual fibers throughout the pulmonary tissue (Figure 19). There were few or no fibers in most areas. Where found, the fibers were present in association with variable sized aggregates of mononuclear cells, small groups of which often appeared to be interstitial (Figure 20). There were, however, some larger fiber-cell aggregates with components that were within air spaces, air spaces now largely obscured by the abundance of cells. The mononuclear aggregates were not arranged into structured granulomata and no giant cells were present. Small amounts of hemosiderin were found in association with fiber aggregates.

Lymph nodes were found to contain fibers occurring in dense aggregates of macrophages. There was wide interanimal variability in the extent of lymph node involvement and the size of lymph nodes within each exposure group.

1.5 x 5 μm Fibers, 20 mg Dose

The lungs of the single animal that died at 40 days post-exposure showed a similar but more intense response than that described below.

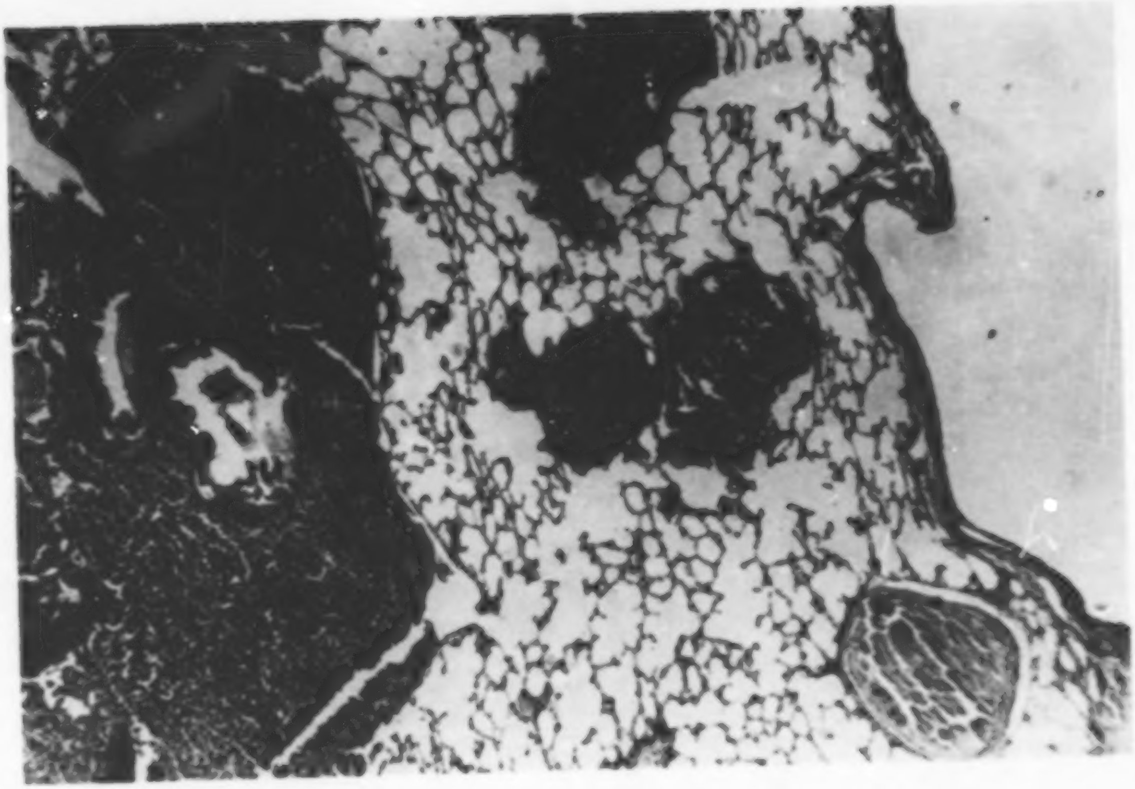

Figure 12.

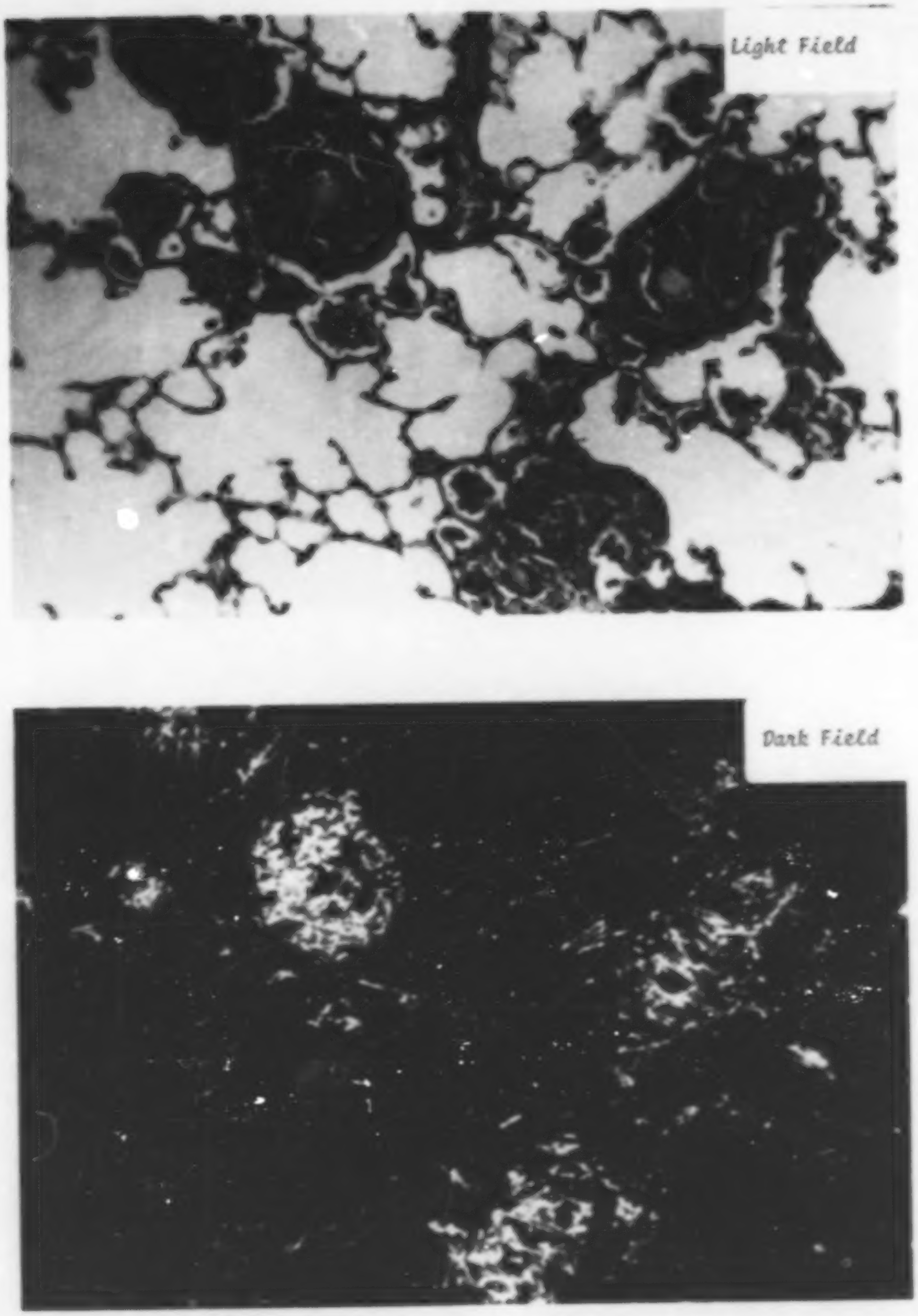
Light Field
Dark Field

Figure 13.

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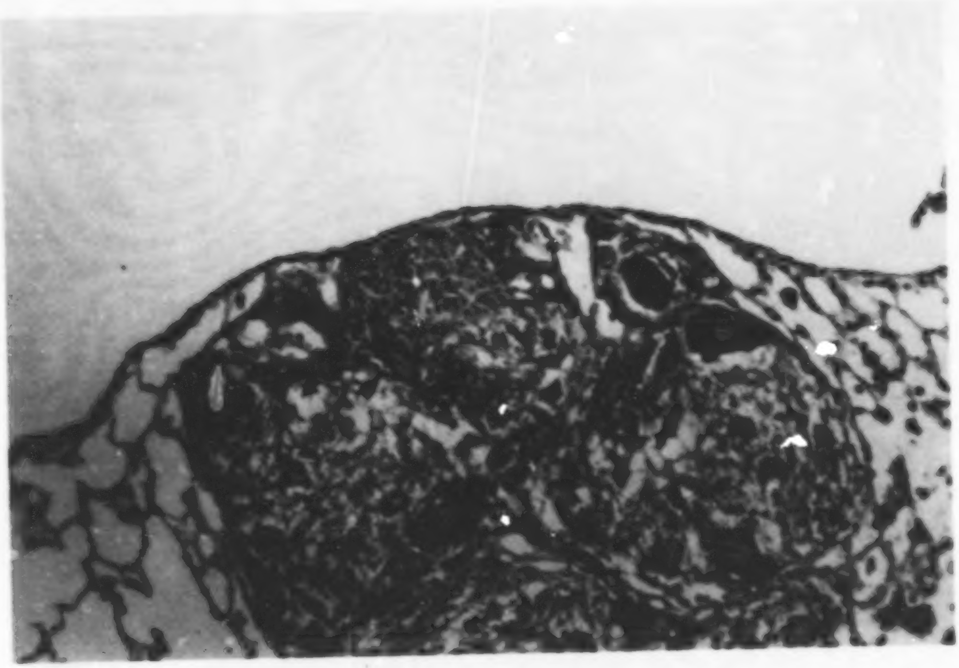

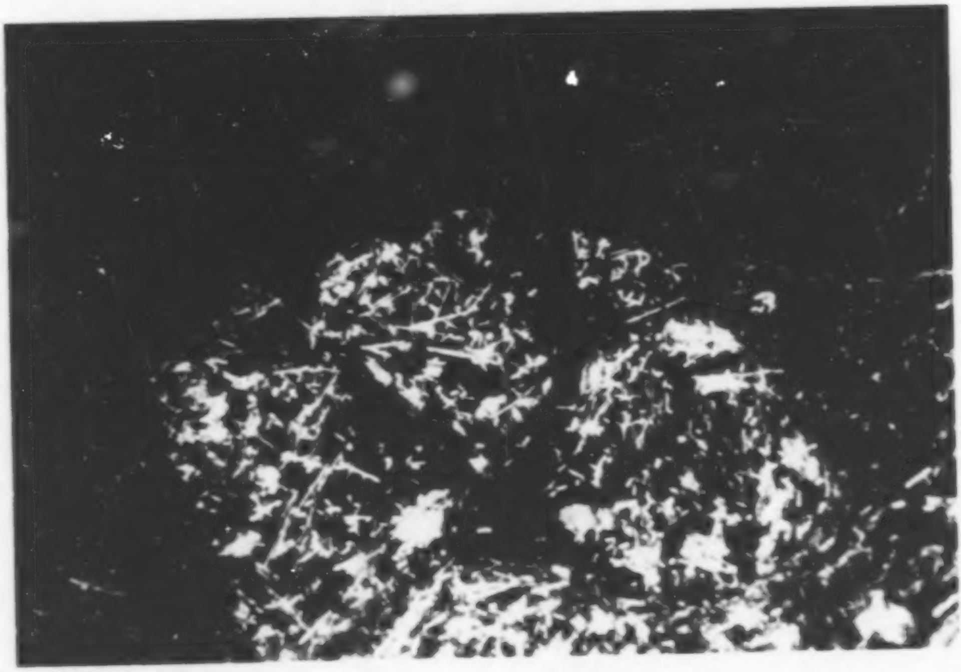

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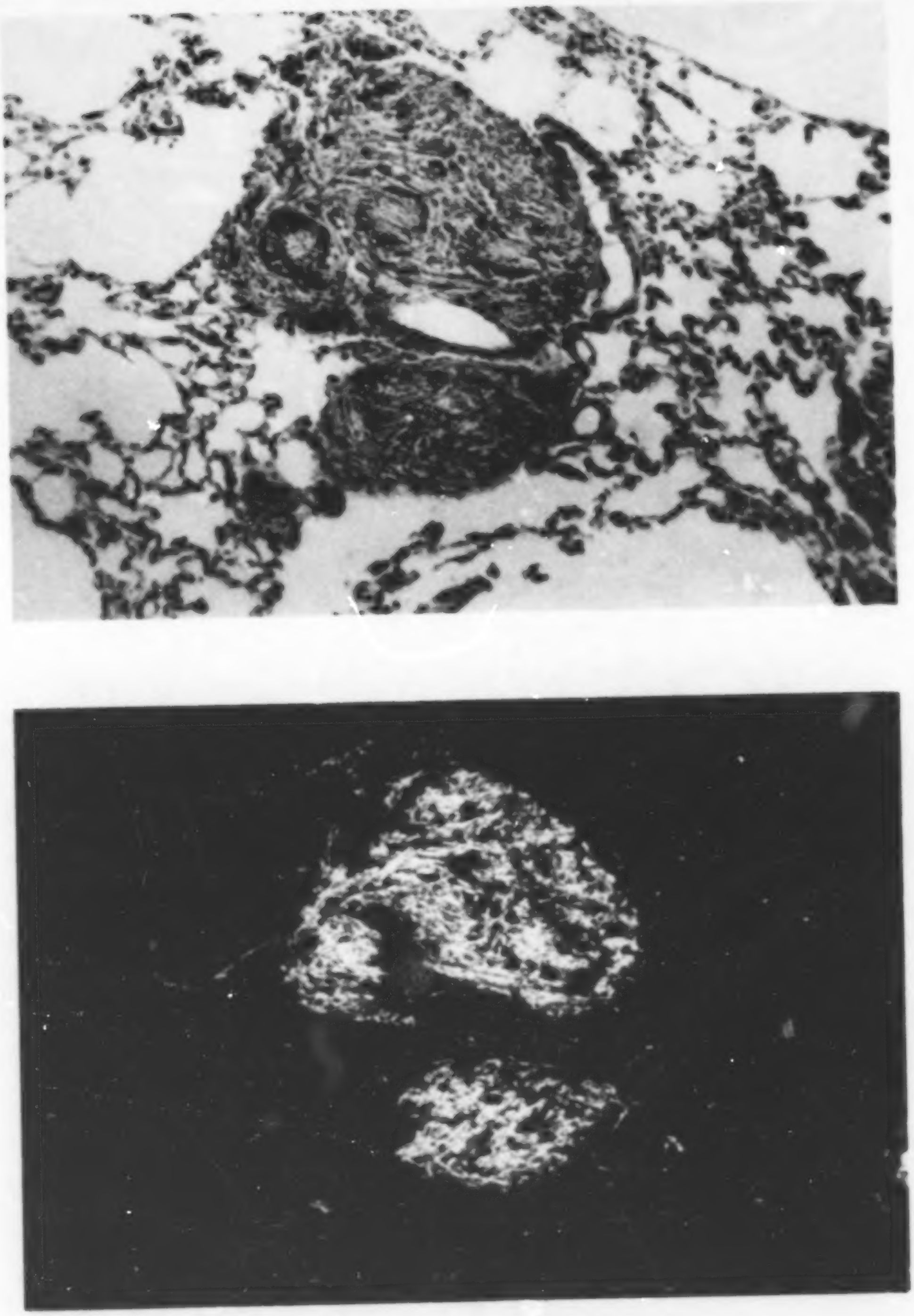

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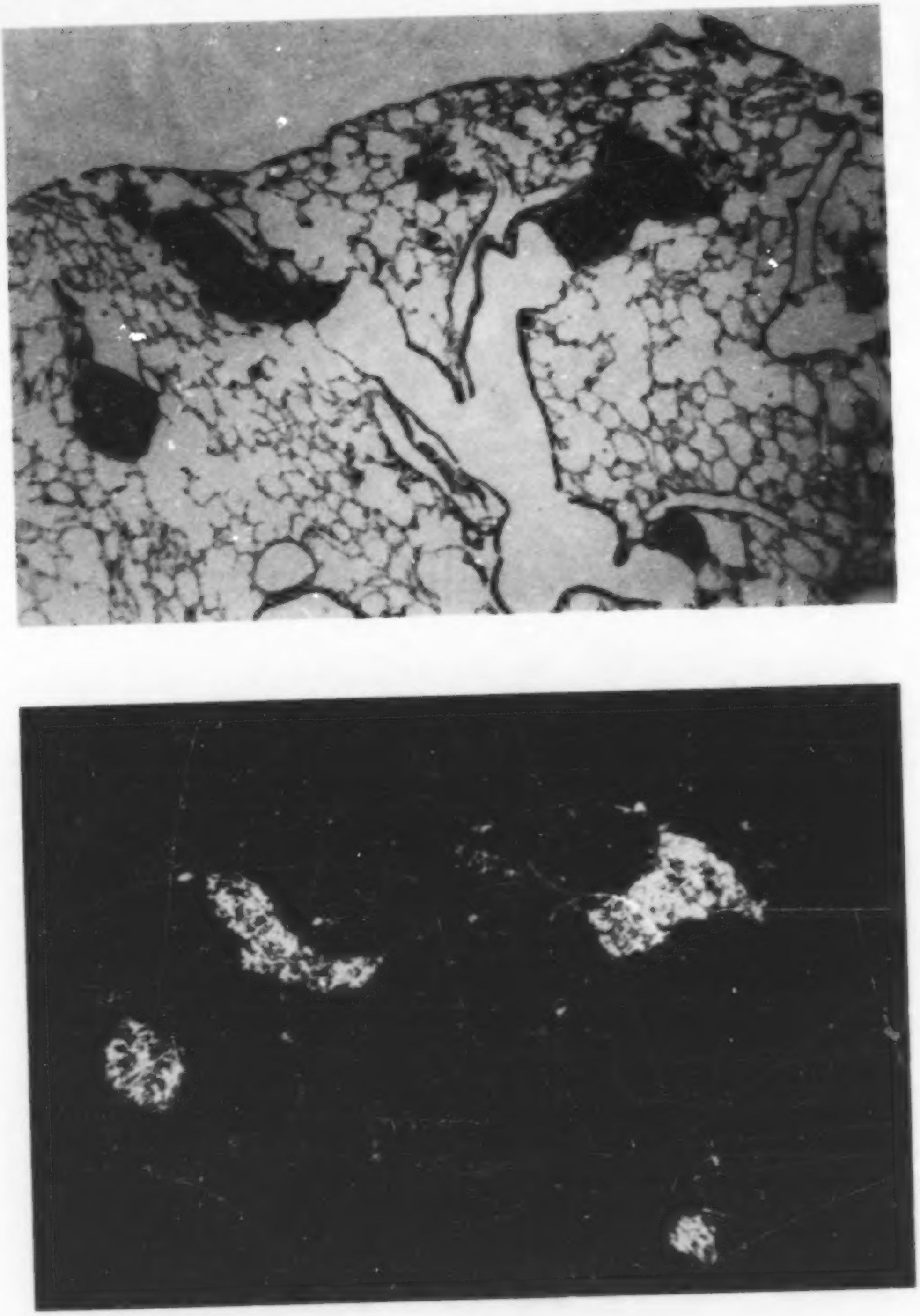

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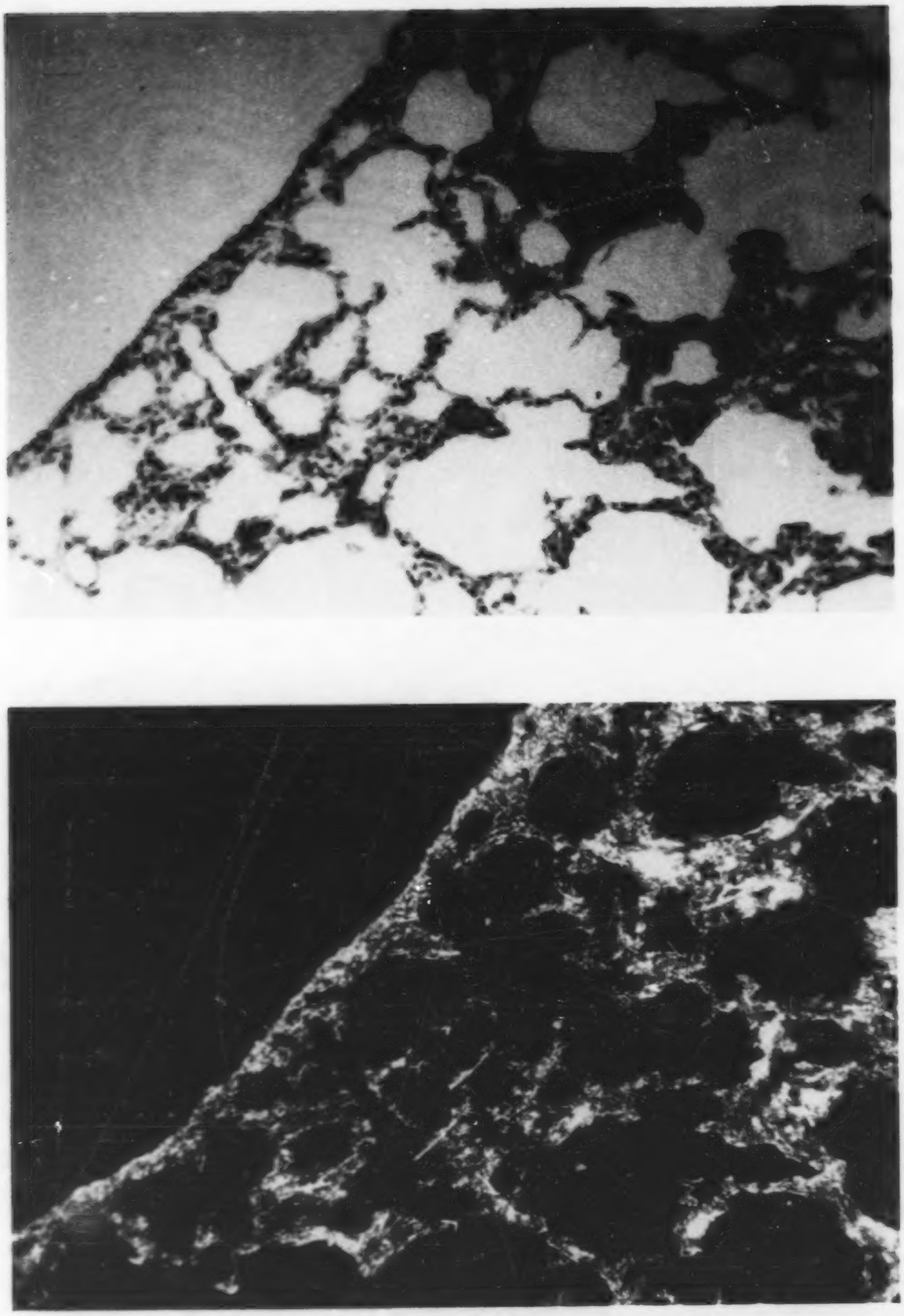

Figure 17.

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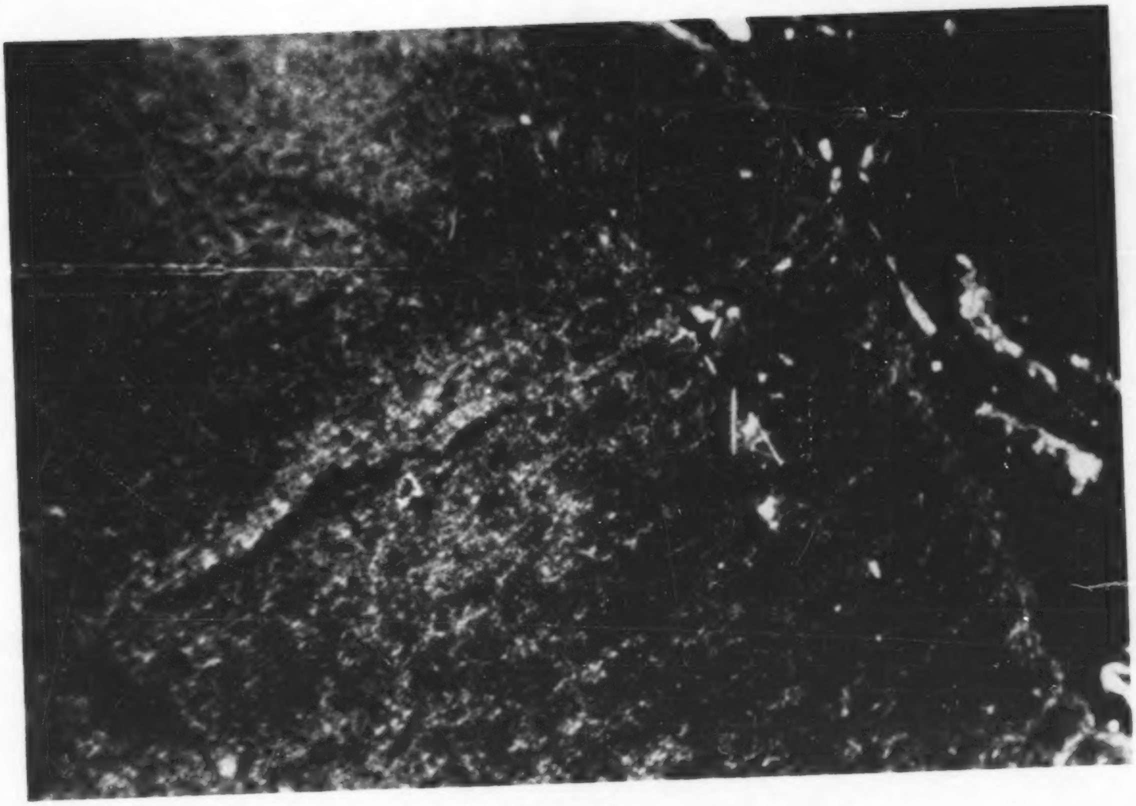

Figure 18.

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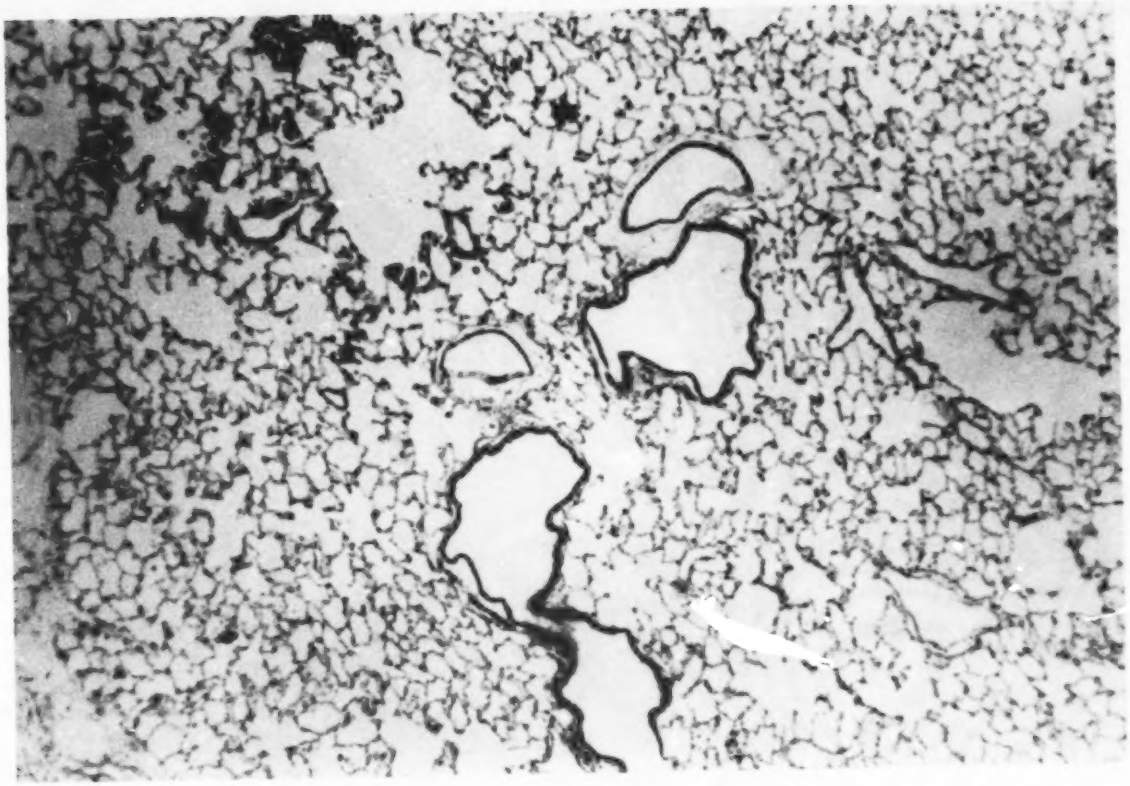

Figure 19.

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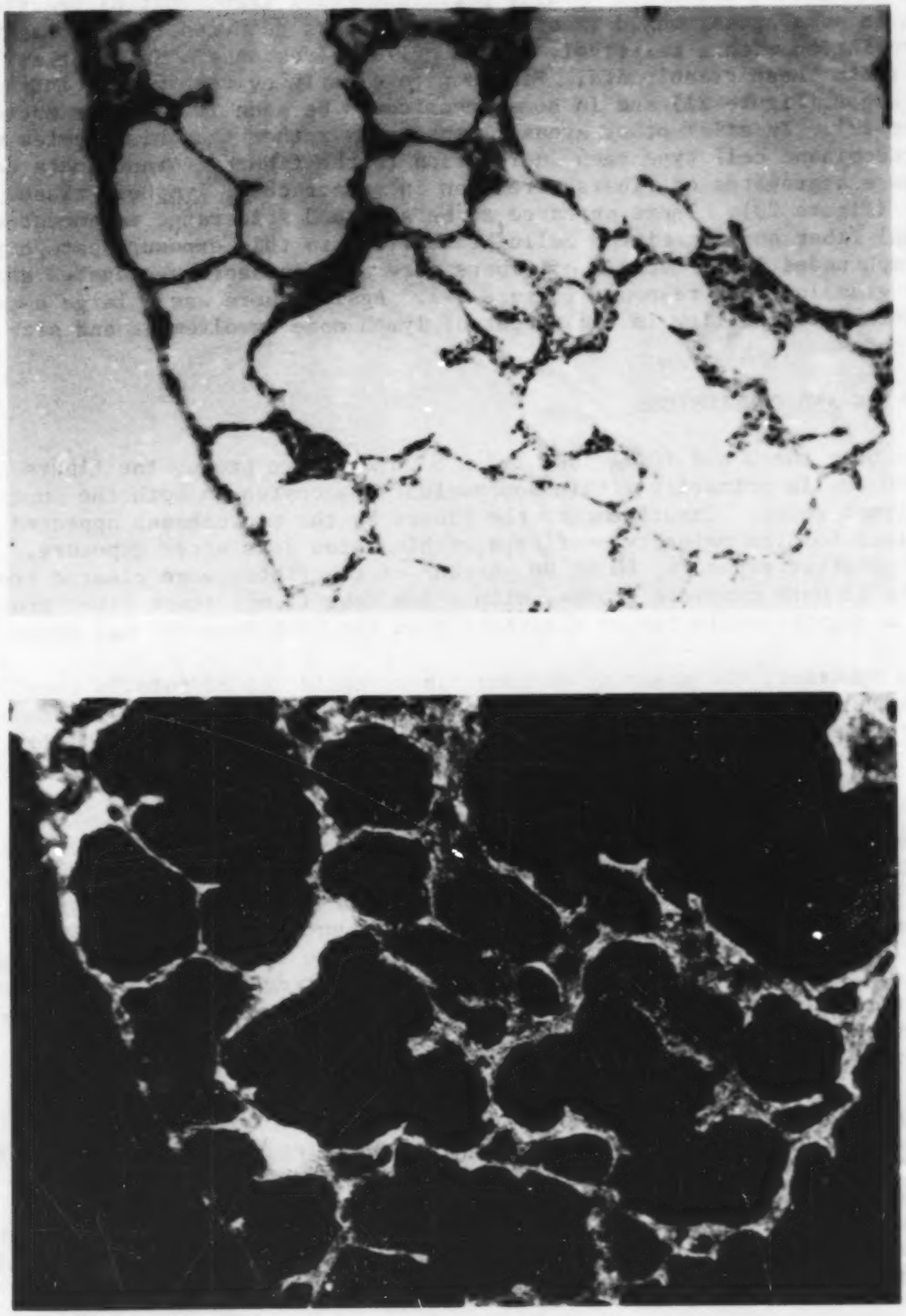

Figure 20.

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Microscopic evaluation of the lungs of the animals from the 6-month sacrifice revealed a distinct, usually peribronchiolar granulomatous reaction to fibers in some areas, while in other areas, fibers occurred in dense aggregates in association with a relatively sparse cellular response. No giant cells were seen within these granulomata. Fibers were clearly evident within interstitial macrophages (Figure 21) and in some areas could be seen in alveolar macrophages (Figure 22). In still other areas, lymphocytes rather than histiocytes were the predominant cell type seen in relation to the fibers. Granulomata containing dense aggregates of fibers were seen in paratracheal lymphoid tissue (lymph sumps) (Figure 23). There appeared to be a 2 to 3 fold range in amount of residual fiber and associated cellular reaction in this exposure category. In the lymph nodes large numbers of fibers were seen in dense aggregates associated with a granulomatous response (Figure 24). Again, there was a large amount of interanimal variability in the extent of lymph node involvement and size of lymph nodes.

DISCUSSION AND CONCLUSIONS

In both the 2 and 20 mg dose 1.5 x 5 µm exposure group, the fibers appeared to lie primarily within mononuclear phagocytes in both the lung and hilar lymph nodes. Engulfment of the fibers by the macrophages appeared to take place for the majority of fibers within a few days after exposure. At ~300 days after exposure, 80 to 90 percent of the fibers were cleared from the rats in both exposure groups, with a low dose (2 mg) short fiber group having a significantly faster clearance than the high dose (20 mg) group.

In contrast, the majority of long fibers could not be totally engulfed by macrophages, nor were they cleared to the regional lymph nodes, although smaller fragments accompanying the long fibers were so cleared. The long fibers produced a striking foreign body reaction, particularly when impacted in the bronchi.

The whole rat clearance curves for animals exposed to the long fiber were different from those for the animals exposed to the short fiber only in the early stages of clearance (<60 days). The majority of both types of fibers were thought to be cleared by way of the mucociliary escalator, however, short fibers were also translocated to the lymph nodes while long fibers did not reach the lymph nodes in significant numbers. Instead, long fibers appeared to be found in foreign body type granulomas. While these differences were apparent from the histological findings the clearance curves were not sensitive to fiber translocations within the rat.

Aggregation of the glass fibers and the consequent impaction of the fibers in the airways seems unavoidable with the single 20 mg dose administered. To circumvent this, another group of rats are currently being exposed to much lower doses of sized fibers by intratracheal instillation repeatedly over several weeks. Comparison of the fiber distribution in the lungs from these two studies as well as the distribution from the inhalation study will help evaluate the validity of these exposures.

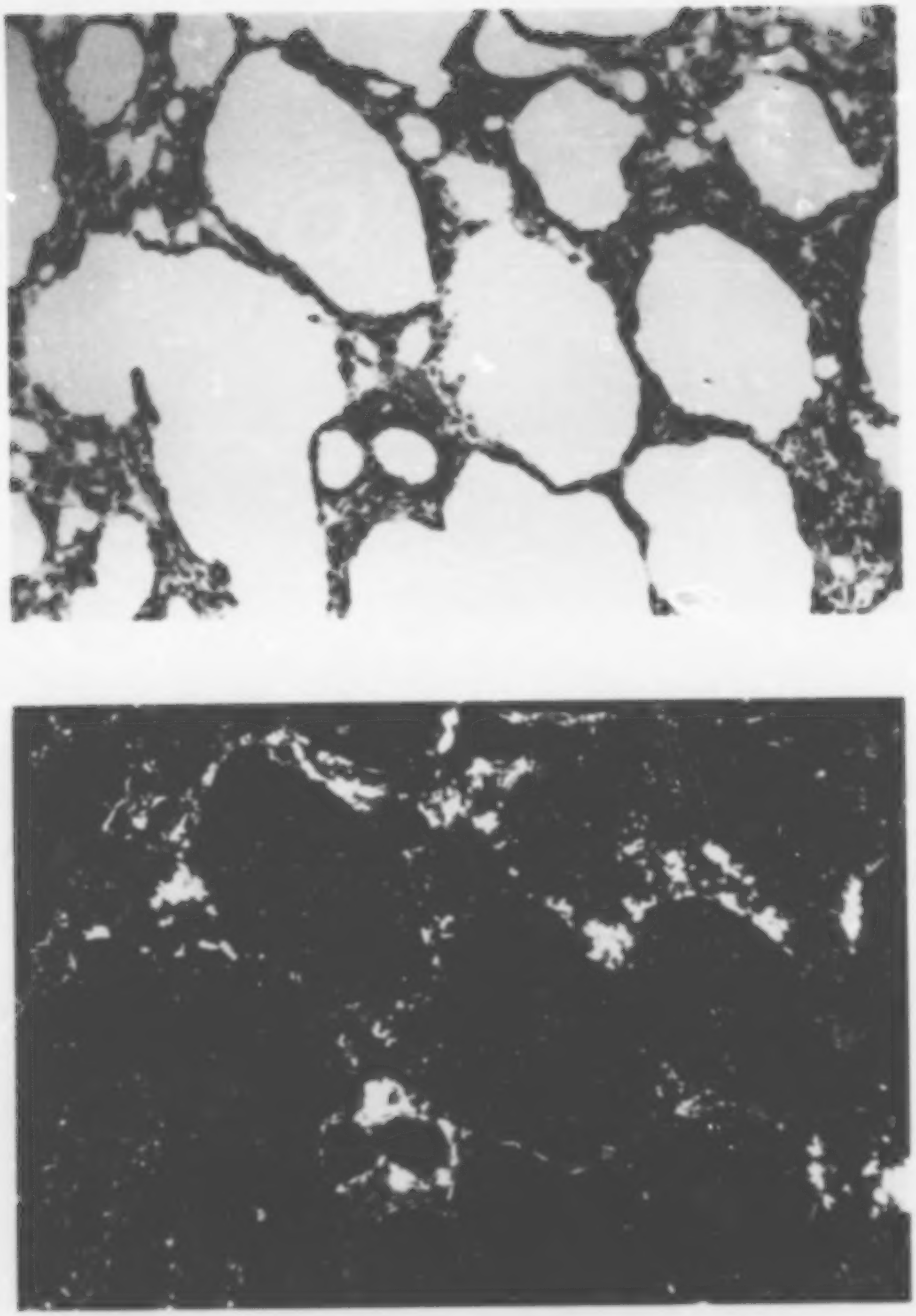
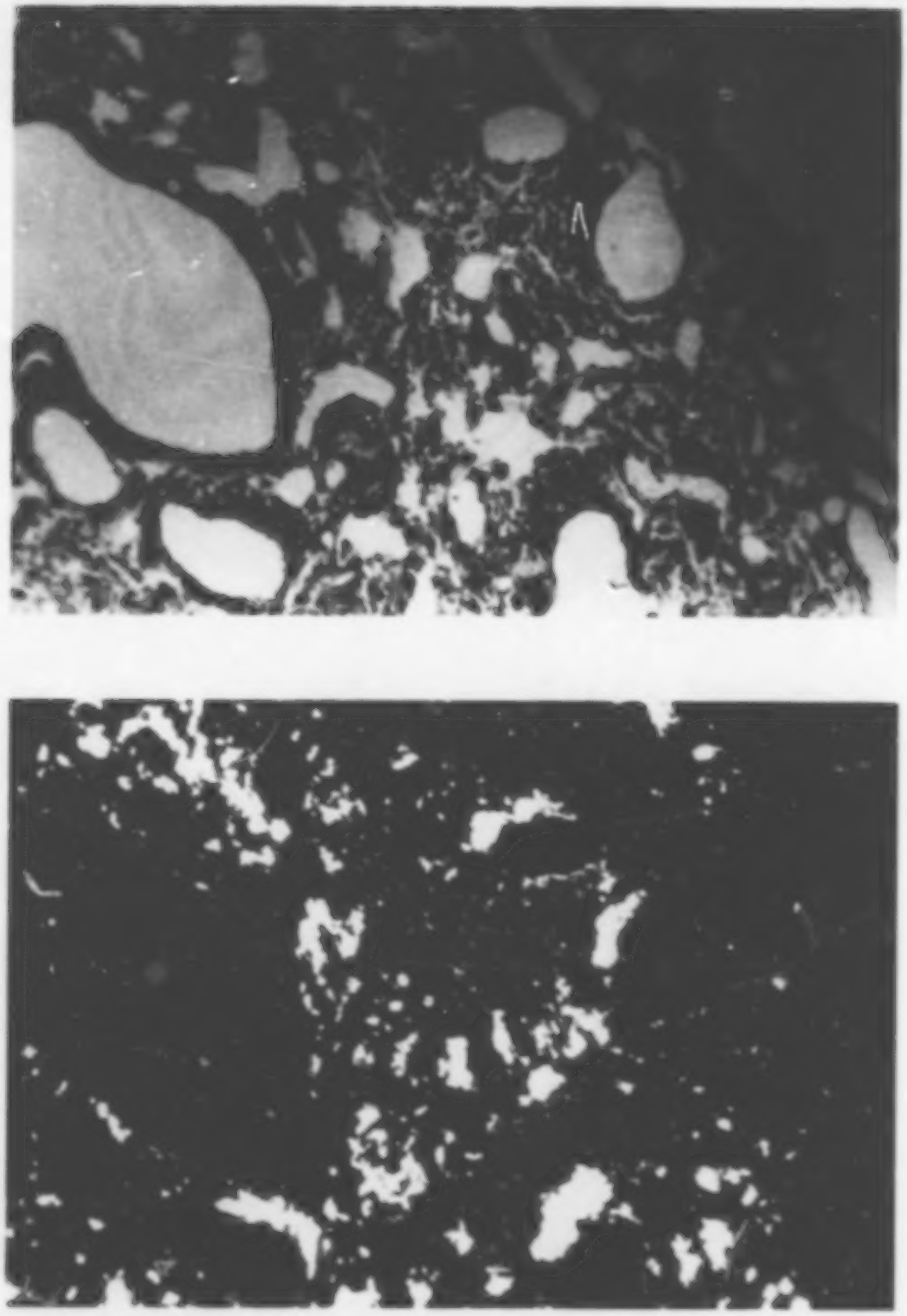


Figure 21.



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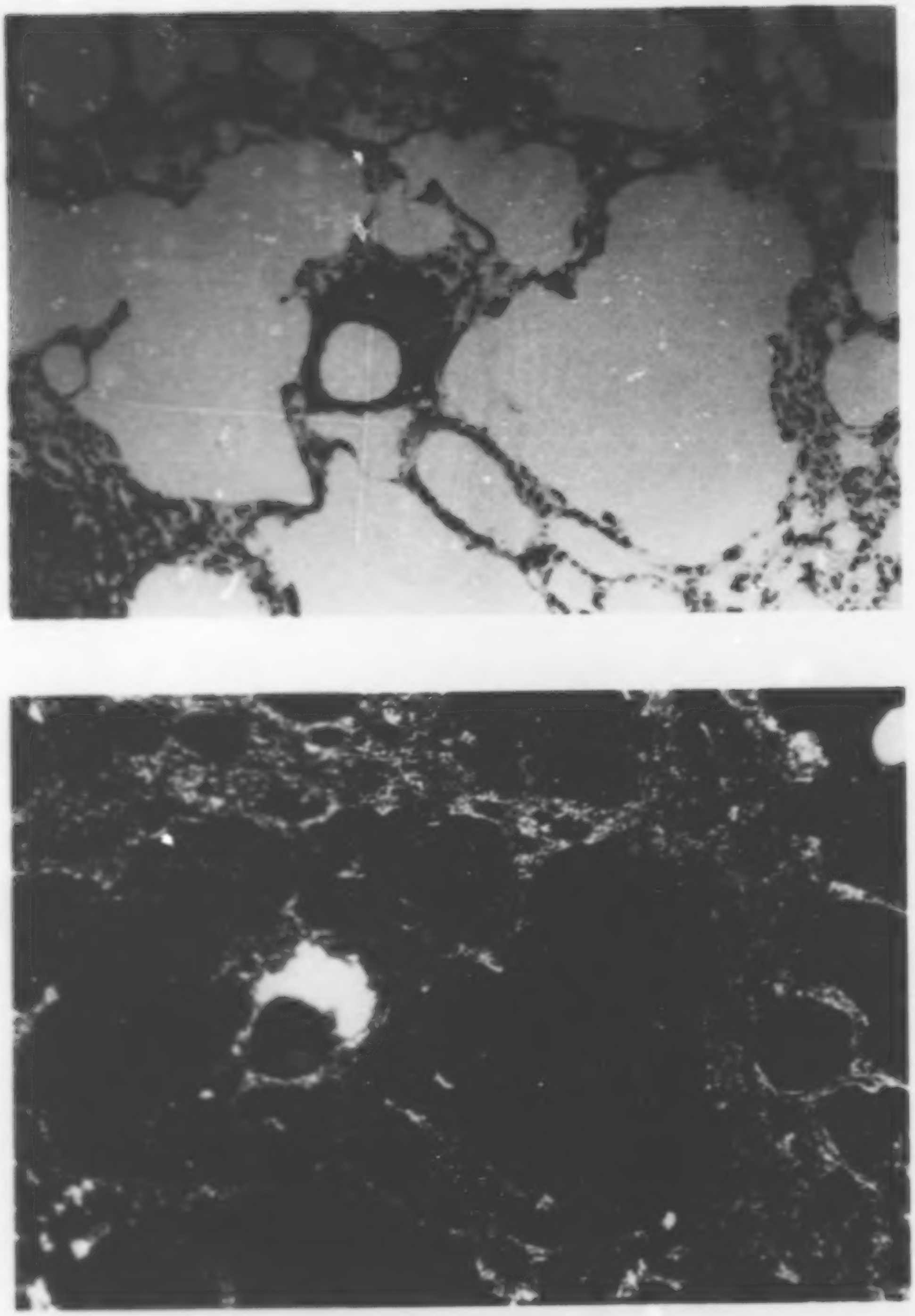

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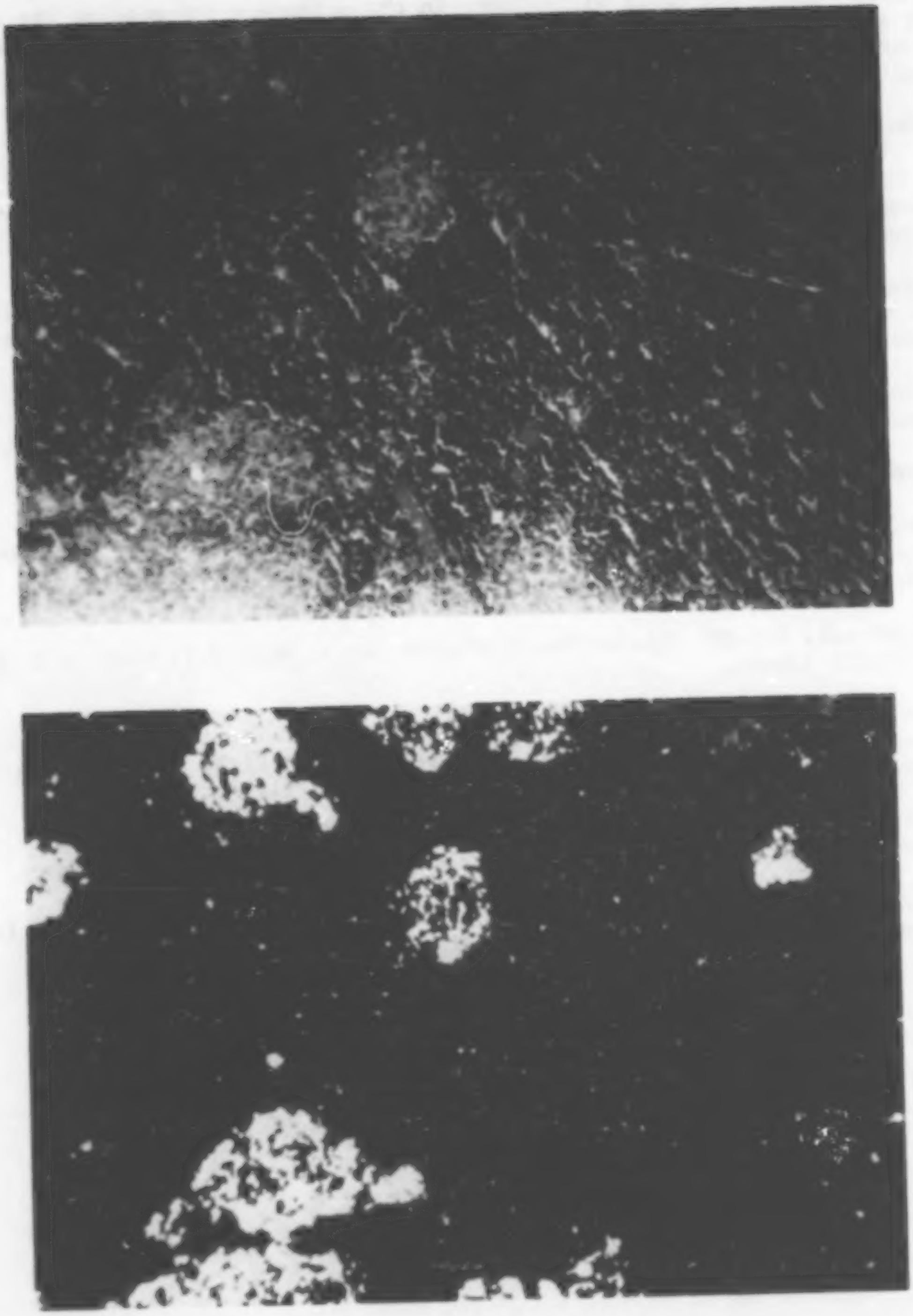

Figure 24.

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While there are clear differences in the pulmonary response to the different size fibers, there is no evidence, thus far, to indicate that either type of fiber produces fibrosis. These studies are continuing, however, with serial sacrifices of four rats/group scheduled at 6-month intervals.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. Robert Peck, Ms. Martine O'Connor, and Ms. Patricia Carr for the analytical and necropsy work and Mr. Charles Bores for data management and computer data processing.

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DISCUSSION ON THE TRANSLOCATION AND FATE OF SIZED MAN-MADE MINERAL FIBERS

QUESTION (Unidentified): I am from the Industrial Health Foundation.

I would like to ask a few questions and make a few comments.

I was very impressed by the parabolic curve that you showed of clearance. That was about a 300-day curve?

ANSWER (Dr. Bernstein): Yes, it was.

QUESTION (Unidentified): And was it similar in the long fibers as in the short fibers?

ANSWER (Dr. Bernstein): For the high dose groups it was as if you looked at the whole curve together. If you break it down into different clearance regions there were differences between the long and short fibers in the early stages and not in the later stages.

REMARK (Unidentified): The conclusion that I would draw from the character of those clearance curves is that the fibers were not imprisoned in a very tight manner over the 300-day period.

QUESTION (Dr. Bernstein): Which fibers?

ANSWER (Unidentified): The long and short. The short fibers certainly were not and the long fibers, according to the character of the curve, showed very little residue at the end of 300 days. The clearance was pretty good compared to the curves that one sees in intratracheal injection of silica, for example, where the injected silica particles are fairly tightly imprisoned within the silicotic nodules. There is an important difference here and it probably reflects the lack of collagenous tissue reaction in the nodules. It reflects the failure of the glass fibers to evoke a fibrotic reaction.

REMARK (Dr. Bernstein): It is clear from our analysis of the histological sections that at six months, there is certainly no fibrotic reaction.

QUESTION (Unidentified): Did you note a significant difference in the size of the granulomas nodule at six months as compared to two weeks?

ANSWER (Dr. Bernstein): No, I did not. I did not do a statistical measurement of it. It is only my own observation. I did not notice it in that time period. It is our feeling that these are not static lesions; that these lesions evolve, new macrophages come in, old ones die and that these do evolve in some way or another over a period of time.

QUESTION (Unidentified): Did you do a similar study of the distribution of injected glass fibers in the lung immediately after the injection?

ANSWER (Dr. Bernstein): Oh, yes. We looked at the distribution in the lung immediately after injection, or a few hours after and it is much more heterogeneous.

QUESTION (Unidentified): It is not a diffused distribution of the fibers, or is it?

ANSWER (Dr. Bernstein): It is really a combination, depending where you look.

QUESTION (Unidentified): You mean they are widely distributed?

ANSWER (Dr. Bernstein): Well, it is varying degrees of fibers throughout many areas of the lung.

QUESTION (Unidentified): What I am pointing to is the statement that Drs. Kuschner and Wright made about the guinea pigs when they indicated that as a result of intratracheal injection, the glass fibers were deposited in irregular manners, in heaps, at the points of bifurcation of the air passages rather than a diffused distribution of fibers as one would expect when the materials are inhaled.

ANSWER (Dr. Bernstein): Perhaps I can answer your question by saying that the distribution we have seen in this study with one 20-milligram exposure is different than what Wright and Kuschner saw and it is also different than what one might expect by inhalation.

QUESTION (Unidentified): Would you say that the difference between your rat results and the guinea pig results in part result from a difference in dosage?

ANSWER: (Dr. Bernstein): I would not like to compare it at this point. We have our rat results for six months and the guinea pig results which were carried out to the two year period of the experiment. At the end of two years I would be better able to compare the two.

REMARK (Unidentified): It seems to me that the important result that you have demonstrated so far is that, at least at the six-month period, there is no evidence of a fibrotic reaction to the presence of the glass fibers, but that there is a foreign body reaction.

REMARK (Dr. Bernstein): That is definitely true and there is definitely a difference in the reaction of the long versus the short fibers in this response.

QUESTION (Unidentified): There are a couple of interesting findings here. The glass fiber is a square cut off at the end. It is not pointy, in other words, and yet that did not prevent the fibers from going through the phagocytes.

ANSWER (Dr. Bernstein): Well, I do not know if the fibers went through the phagocytes or the phagocytes tried to engulf the fibers.

QUESTION (Unidentified): Right. But the fibers seemed to be continuous through the phagocyte?

ANSWER (Dr. Bernstein): Yes.

QUESTION (Unidentified): All right. Being cut off square did not prevent this process from occurring?

ANSWER (Dr. Bernstein): Well, I do not know that a phagocyte knows anything about being cut off square or how long the fiber is.

REMARK (Unidentified): I know, but this is important in terms of comparing one type of fibrous material and another type.

ANSWER (Dr. Bernstein): Well, they are not really square. The early scanning pictures that I showed you in very high magnification of the edges showed that they are fairly jagged. The macrophage theoretically may see the end of the particle and say, hey, that is a particle I can phagocytize, and then try to do it. It may see the diameter when it comes in head-on perpendicular to the fiber and say, yes, I can phagocytize that too. It does not know that it cannot, by the mechanisms of information that is transmitted to the macrophage. It seems that when you have fibers of too large a diameter the macrophage does not try to engulf it. It knows it cannot in a sense.

REMARK (Unidentified): You point out also in the abstract that the long fibers are found in the pleural cavity but the short fibers are not.

ANSWER (Dr. Bernstein): I qualified that a little more carefully in my talk by saying that this is a preliminary result. We have a more elaborate study going on now to look at this in detail. The preliminary results did indicate this and the more elaborate results will tell us more.

QUESTION (Unidentified): Will you be looking for the potential formation of mesothelioma?

ANSWER (Dr. Bernstein): Yes. That is one of our end points.

REMARK (Mr. Ashford): I am from the Massachusetts Institute of Technology.

I think Dr. Bernstein has been very careful in terms of stating the limitations on what conclusions can be drawn from the data and I would, just as a student of regulatory history, caution you not to take great heart from the fact that the 6 month data do not indicate a real problem. The reason I say this is, first, there will be some problems relative to the inhalation characteristics which Dr. Bernstein has found, and second, I do not think taking great heart in the science of this point is going to do the industry very much good. It would be very good to have alternative technologies in mind, changes in terms of the fiber lengths that are produced by the fiberglass industry and other issues rather than waiting until the data come in and then act surprised. I just think that one has to be careful when one views the preliminary results.

ANSWER (Dr. Bernstein): I would say that until the results are in there is no way I can give an opinion as to what is going to be happening.

QUESTION (Mr. Wright): I work for the Steel Workers Union in the Safety and Health Department.

I have a technical question. I know your study did not concern this problem but it is an interesting one. Have you or has anyone else looked at the clearance of particles from the silicated portion of the bronchial tree? The reason I am asking that is to try to figure if there is any evidence indicating that the lung's clearance mechanism for that portion might be less efficient for long fibers than it is for shorter fibers or for non-fibrous material.

ANSWER (Dr. Bernstein): Well, the only thing I can do is to give you a comment based on the indirect measurements that we have looked at. Those are in terms of whole rat clearance.

If one looks at the histological results and sees that there are a fair number of short fibers going to the lymph nodes, that is included in the whole rat measurement. When one looks at the long fiber group and sees that very little is going to the lymph node and not that many are going anywhere else, it seems that even the silicated mucous transport mechanism is more efficient in clearing the long fibers than the short fibers because the clearance curves indicate approximately the same quantity left in the rat at the end of 300 days.

OCCUPATIONAL EXPOSURES
TO MINERAL WOOL

by

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INTRODUCTION

The bulk of the work to be presented here was performed during the period 1976-1978 under Contract Number 210-76-0120 with the National Institute for Occupational Safety and Health. In addition to the work performed for NIOSH, substantial work has been undertaken in the U.S. by the Thermal Insulation Manufacturer's Association (TIMA) and in Europe by the Joint European Research Board (J.E.M.R.B.). This work will be briefly mentioned as well. The readers interested in the general questions associated with man-made mineral fibers in the environment should consult the review prepared by Corn (1979).

BACKGROUND

Mineral wool is a generic term that denotes any fibrous glassy substance made from minerals (e.g., natural rock) or mineral products (e.g., slag or glass). For the purpose of this presentation, mineral wool has been defined to include only those fibers made from natural rock (rock wool) or from slag (slag wool), thus fibrous glass is excluded.

Mineral wool has been produced and used for over a century. Thoenen (1939) reported that mineral wool was first produced in Wales in 1840. Production began shortly thereafter in Germany. The first U.S. mineral wool plant began operation in Cleveland, Ohio in 1888. In 1890, a plant was in operation in Salem, Virginia. The first successful commercial production operation was started in 1897 by C. C. Hall in Alexandria, Indiana. The product began to find a substantial market by the end of the first world war (Pundsack, 1976). By 1939, there were 71 companies operating 82 plants manufacturing slag, rock, and glass wool.

In the late 1930's Corning Glass Works and Owens-Illinois joined forces to become Owens-Corning Fiberglas; and the company invested heavily in technology to produce glass wool by processes superior to those that had been used in the past. The paths of rock wool and glass wool partially diverged at this point--the rock wool and slag wool manufacturers continued mainly with the processes and markets of the past, and the glass wool manufacturers opened new markets, including textiles (Smith , 1976). However, the two products continued to compete in the thermal insulation market.

The basic process by which mineral wool is made today is similar to that used in the 1890's. The raw material (slag and/or natural rock) is loaded into a cupola in alternating layers with batches of coke and small amounts of other raw materials used to give the fibers special characteristics of ductility or size. The coke is burned, generating high temperatures and melting the slag. The molten stream of slag issues from a hole in the bottom of the cupola and is "fiberized." Currently, approximately 70 percent of the mineral wool sold in the United States is produced from blast furnace slag. A small amount is produced with natural rock, which is also usually added to the slag to impart desired qualities of flexibility to the fibers.

In the past, the usual practice was to direct a stream of steam (or of air) to intercept the falling stream of slag, breaking it into many small globules which then "tailed out", producing fibers with a semi-spherical head. The heads broke off as the material cooled, producing fibers and "shot" (the cooled heads).

Currently, most of the mineral wool in the United States is made by variations of the Downey process. The stream of molten slag or rock falls onto a spinning rotor and the partially fiberized slag or rock is further attenuated by an annular stream of steam or air. The "dry spinning" process is used by a minor fraction of the producers. This is a mechanical attenuation process that does not use fluid attenuation for additional separation.

As the fiber is formed, it may be further treated to increase its utility for one or more of its intended uses. In general, these treatments are applied immediately following the rotor, by the atomization of liquids that are "sprayed" onto the newly formed fibers. In almost all cases, an oil will be applied in this manner to reduce the "dustiness" (tendency to become airborne) of the bulk products.

Where the mineral wool product to be produced is required to have moderate or substantial structural rigidity or stability (as in equipment insulation and building insulation batts and blankers), a "binder" (usually a phenol formaldehyde resin) may be added immediately following or in place of the oil treatment. The mineral wool may then be compressed into "batts", "blankets" or "boards" or left loose as "wood".

Those products that are to be used without additional covering (such as high-density equipment insulation and some residential insulation batts) are packed for shipment. Other products require further covering, for example, residential structural insulation is often covered with a vapor barrier (e.g., Kraft paper treated with asphalt or aluminum foil) on one side and untreated paper on the other side. For industrial insulation (e.g., boilers), a wire mesh covering is often added.

MINERAL WOOL USE

Mineral wool is widely used in structural and industrial insulation products, as well as in cements, mortars, ceiling tiles, and other products where its characteristics of thermal and structural stability are desirable. The products in which mineral wool is used include:

- "Blowing" wool and "pouring" wool, loose bagged wool (either granulated or not) that can be blown by pneumatic blowers or poured by hand into residential or commercial building structural spaces.
- Batts and blankets, relatively loose and light (low density) material shaped to file between structural members of residential or commercial buildings.
- Cement, mortar, or ceiling tile. Producers of these products add bulk fiber to their product to impart structural strength and qualities of fire resistance and thermal and sound insulation.
- Industrial and commercial insulation products for covering pipes, ducts, boilers and other equipment. High density material with significant amounts of binder added.
- "Fireproofing" to be sprayed upon steel girders in buildings.
- Miscellaneous small volume uses; in friction materials, reinforced plastics, etc.

Transportation costs are a significant fraction of the costs of insulation products; to reduce these costs, the industry has become highly regionalized. The most directly competitive product is fibrous glass.

In some areas of the U.S., mineral wool is the predominant mineral fiber insulation material, while in others fibrous glass predominates. Because of its greater density, mineral wool is a more effective sound insulator than fibrous glass, and is thus often specified in industrial applications. However, this greater density can be a drawback in the insulation of residential and commercial structures, particularly where framing is light and the required thermal insulation effectiveness is high.

Fibrous glass has steadily increased its share of the total insulation market over the past 30 years. If the insulation market is examined in detail, it can be seen that the most probable future market for mineral wool is in the industrial sector, with relatively limited usage in residential and commercial products. In general, the residential and commercial market fraction for mineral wool is continuing to decline, with strength only in those regions where it has marked economic advantages over fibrous glass. This trend is expected to continue, with mineral wool consolidating its position in the industrial market and gradually relinquishing part of its present share of the commercial and residential insulation market. It may be expected that mineral wool will find increasing use as a substitute for asbestos, as asbestos is "phased out" of some industrial products because of its known adverse health effects. Thus, it may be expected that those workers who have been exposed to asbestos in the past may in the future be exposed to mineral wool fibers.

HEALTH EFFECTS OF MINERAL FIBER EXPOSURE

The health effects attributable to mineral fibers have been the subject of major international conferences in the past 10 years (New York, 1964; Dresden, 1968; Lyon, 1972). Other conferences such as the Johannesburg conference in 1969 and the ILO Helsinki conference in 1971 have also devoted substantial portions of time to the same and associated topics.

The majority of these reports, however, deal with only one category of mineral fibers, asbestos. [We will set aside, for the moment, Harington's (1975) objection to the use of "mineral fiber" as a generic term to include the amorphous man-made fibers.] Little attention has been paid to the health effects of other mineral fibers with the exception of limited work on fibrous glass.

Health Effects of Asbestos

Cancer--

The most serious potential consequence of mineral fiber exposure is the development of cancer. An increased incidence of the following tumors has been associated with human exposure to asbestos:

Tumor	Selected Epidemiologic Evidence
Lung Cancer	(Doll, 1955; Knox, 1968; Selikoff, 1973)
Mesothelioma (Pleural & Peritoneal)	(Bohlig, 1973; Newhouse, 1973)
G.I. Cancer	(Selikoff, 1973)
Laryngeal Cancer	(Stell, 1973; Newhouse and Berry, 1973)

Fibrotic Lung Disease (Asbestosis)--

There is no need for further documentation of asbestosis in humans; such documentation exists in scores of studies. Although the attack rates have varied from study to study (and for type of asbestos fiber), it is clear that inhalation of any form of asbestos will, given sufficient doses, lead inevitably to asbestosis in a significant fraction of the exposed population. The universality of the response can be seen in the table on pages 364-365 of Harington's (1975) review.

Health Effects of Fibrous Glass

The only exposure-specific population studies that have been carried out on the consequences of exposure to mineral fiber other than asbestos have been on fibrous glass. The studies (Wright, 1968; Nasr, 1971; Utidjian, 1970;

Gross, 1971) did not address the question of malignancy. They concluded from pulmonary function (Utidjian), radiographic (Wright and Nasr), and post-mortem (Gross) studies that there were no significant effects from occupational exposure to fibrous glass. A discussion of these studies was presented in an article by Dement (1975). A study by Enterline (1975) examined the mortality experience of a cohort of 416 men who retired during the period 1945-1972 from six fibrous-glass manufacturing plants. Enterline found "no evidence of an excess in respiratory cancer mortality. No mesotheliomas were noted." For 115 of the men, the stated retirement cause was disability. Comparing this with the expected distribution, Enterline found "...no evidence of any unusual health hazards, with the exception of a possible excess in chronic bronchitis."

These and other studies were reviewed in-depth in the preparation of the NIOSH Criteria Document on Fibrous Glass (NIOSH, 1977). Upon consideration of human health studies and animal tests, NIOSH concluded that two categories of fibrous glass could be defined--those fibers larger than 3.5 micrometers (μm) diameter and those less than 3.5 μm. For the former, it was concluded:

> The primary health effects associated with the larger diameter fibers involve skin, eye, and upper respiratory tract irritation, a relatively low incidence of fibrotic (lung) changes, and preliminary indication of a slight excess mortality risk due to non-malignant respiratory diseases. In this regard, NIOSH considers the health hazard potential of fibrous glass to be greater than that of nuisance dust, but less than that of coal dust or quartz.

The Criteria Document goes on to address the potential problems associated with small diameter fibers. The laboratory animal implantation studies of Stanton (1972, 1977) were examined and it was concluded that these results could not be extrapolated directly to conditions of human exposure. The document continued:

> On the basis of currently available information, NIOSH does not consider fibrous glass to be a substance that produces cancers as a result of occupational exposure. However, these smaller fibers can penetrate more deeply into the lungs than larger fibers and until more definitive information is available, the possibility of potentially hazardous effects warrants special consideration.

On the basis of these considerations, NIOSH recommended an environmental (workplace air) concentration limit of 3 fibers/cm^3, determined as a time-weighted average concentration for up to a 10-hour work shift in a 40-hour work week. Only those fibers with a diameter less than or equal to 3.5 μm and a length equal to or greater than 10 μm are covered by the recommended limit. Additional recommendations involve medical examinations and record keeping.

Health Effects of Mineral Wool

It has been assumed previously that fibrous glass and rock (or slag) wool could be appropriately grouped together in a discussion of the health effects of mineral fibers. No reported studies of those exposed only to rock wool or slag wool are known, although Enterline is currently carrying out such a study, sponsored by the Thermal Insulation Manufacturers Association (TIMA), (Konzen, 1980), as is NIOSH (Ness, 1979). No firm evidence exists from which the health effects of rock wool or slag wool can be predicted. The evidence most clearly indicating potential exposure risks associated with mineral wool is the work of Stanton et al. (1972, 1977), Kuschner and Wright (1976), Pott et al. (1976) and Davis (1972). In these laboratory studies, it has been found that long ($\gtrsim$ 10 μm), thin ($\lesssim$ 1 μm) fibers have greater biological potency (tumorigenicity, fibrogenicity) than shorter or thicker fibers, regardless of the chemical composition of the fibers. This indicates that these long, thin fibers are probably of greatest concern in human exposures to mineral wool. Figure 1 is an adaption of some of Stanton's data, showing the effect of increasing the fraction of long, thin fibers in implanted fibers on the probability of tumor response in animals (Stanton, 1977)

Comparability of Results for Other Fibers: Extrapolation to Mineral Wool

There is convincing epidemiological and case report evidence that asbestos, upon inhalation, is fibrogenic and carcinogenic in man. Fortunately, no such convincing human evidence exists for other mineral fibers. It is difficult to extrapolate from the results for asbestos to predict human health effects from exposure to mineral wool. The work that has been done with fibrous glass is more directly applicable, but there are still many areas of uncertainty. The NIOSH decision (in regard to the recommended environmental standard for fibrous glass) that "...until more information is available, the recommended standard can also be applied to other man-made mineral fibers..." seems appropriate with respect to mineral wool. The two recent NIOSH publications (1976, 1977) dealing with fibrous glass are recommended as background reading on the health effects of mineral wool, as are the Copenhagen Workshop Proceedings (JEMRB, 1977).

One aspect of the potential problem associated with the human exposure to this material has been a suggested demand for small fiber diameter. Figure 2 shows the effect on bulk thermal conductivity (the inverse of insulation effectiveness) of fiber diameter in these products. Because of the costs associated with attaining smaller fiber diameters, most U.S. commercial products, particularly those used in home insulation, have a median fiber diameter near 4-5 μm. In Europe, however, and particularly in the Soviet Union, mineral wool fibers are being commercially produced with median fiber diameters <1μm (SRI, 1976). Some interest has been expressed in these processes by U.S. producers.

The characteristics of fibers produced by the various processes is not uniform, however, and a substantial fraction of fibers in mineral wool entering commercial use in the past may have been less than one micrometer in diameter as shown in Figure 3. These represent bulk samples obtained from residential and commercial installations (in the period from 1937 to 1976) by an insulation firm in the Dallas area. As can be seen, the diameter distributions are widely variant. We cannot be certain that the small diameter fibers

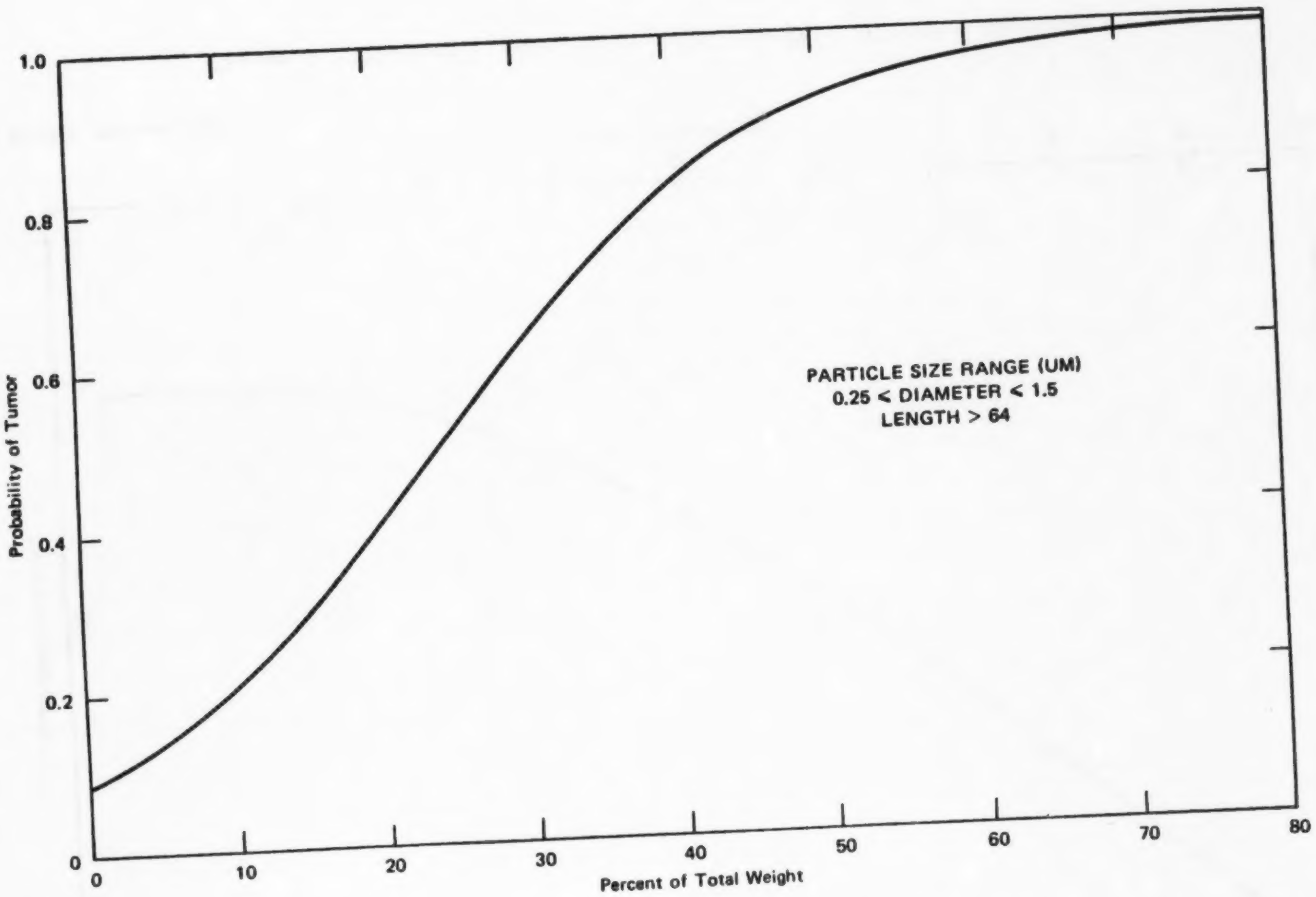

Figure 1. Probability of tumor versus percent of implanted particles in size range.*

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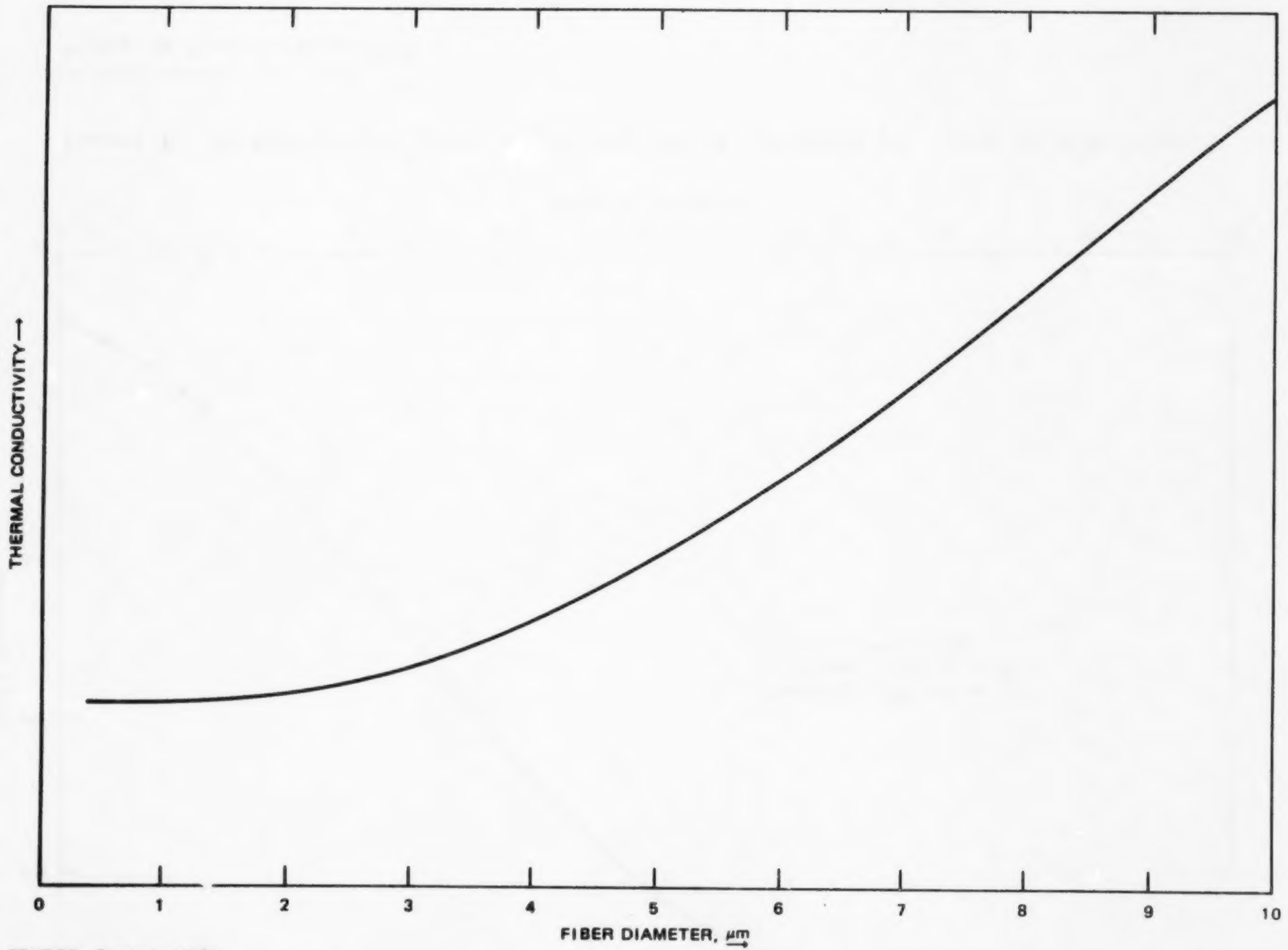
*Adapted from Stanton, 1977.



SOURCE: Pundsack, 1976

Figure 2. Thermal conductivity as a function of fiber diameter.

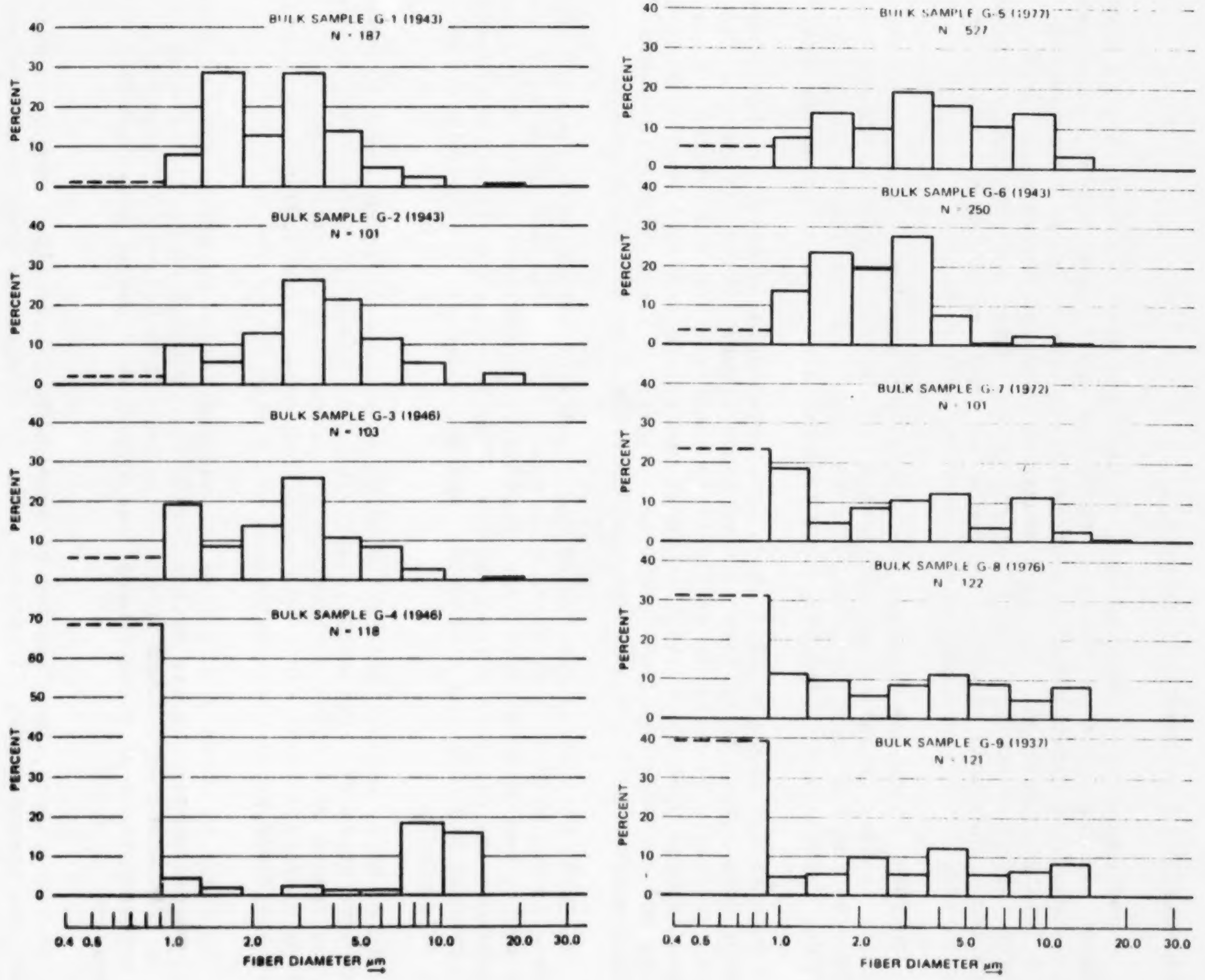


Figure 3. Frequency of occurrence of fibers of specific diameter in mineral wool samples.

shown are not asbestos. Admixture of asbestos with other insulation materials was apparently practiced from time to time in the past. In addition, the producers and users of mineral wool products also commonly produced and used asbestos-containing products, and exposures were mixed. Asbestos exposure is thus a confounding variable in assessment of health effects due to exposures to mineral wool in the past.

PRIOR STUDIES OF OCCUPATIONAL EXPOSURES

Human exposures to mineral wool fibers have been examined only in a few studies. In the first of these, by Carpenter and Spolyar (1945), dust concentrations in a mineral wool production plant were measured by Greenburg-Smith impingers in 1934. The dust counts so measured ranged from 12-26 million particles per cubic foot (mppcf) with limited dust control equipment installed. When more effective controls had been installed, a resurvey by the same investigators found dust concentrations of 5-10 mppcf.

In 1962, Sheinbaum reported the preliminary results of surveys in the building trades, including the application of "asbestos-rockwool cement" as a fireproofing and sound insulation agent. He found "extremely dusty conditions," with average breathing zone impinger dust counts "about 200 mppcf."

Both of the above studies share a major disadvantage--the method of measurement does not differentiate between mineral wool fibers and general particulate material. Thus, it is difficult to ascertain how much of the inhalation burden imposed upon the workers in these operations resulted from mineral wool fibers and how much resulted from other material. Total particulate mass concentrations and fiber size were not determined in the above studies.

In 1976, Corn et al. published the results of extensive industrial hygiene surveys in two mineral wool production plants. With the use of personal sampling pumps, measurements were made of total suspended particulate matter concentrations and of fiber concentrations. The latter analysis was performed with optical and electron microscopy, and the sizes of the fibers observed were determined.

In Plant A, ceiling and wall panels and tiles containing about 50 percent fiber were produced. Optically visible ($\gtrsim$ 1 μm diameter) total fiber concentration ranges were 0.2-1.4 fibers/cm^3; electron microscopically visible ($\lesssim$ 1 μm diameter) total fiber concentrations ranged from 0.0056-0.16 fibers/cm^3. Total suspended particulate material levels were 0.53-23.64 mg/m^3.

In Plant B, where specialized thermal insulation materials were produced, total suspended particulate matter levels were 0.045-6.88 mg/m^3. Fibers $\gtrsim$ 1 μm (diameter) were found in concentrations from 0.11-0.43 fibers/cm^3. The concentrations of those fibers less than 1 μm diameter were 0.0059-0.089 fibers/cm^3.

In both plants, the fraction of respirable fibers (less than 3 μm diameter) was approximately 75 percent. The total airborne dust concentration (mg/m^3) was found to be a poor indicator of airborne fiber (fibers/cm^3) concentration.

Esmen, et al. (1978) recently presented data upon the occupational exposures in five mineral wool plants, including the two (mentioned above) discussed by Corn, et al. in 1976. Their general findings were that "the results of the study indicate that the average exposure is about 0.1 to 0.5 fibers/ml. The results also indicate that despite operational diversities among the plants the size and length distributions of airborne fibers were consistent. It was also found that there is an excellent correlation between average total suspended particulate matter and average fiber exposure for types of work activity found in the plants..." Although the last statement may appear to conflict with their conclusion in the previous study, it should be noted that they refer to excellent correlations of average concentrations as opposed to poor correlations of individual (matched) concentrations in the previous work.

Recent European studies were discussed at a workshop in Copenhagen (JEMRB, 1976). It was stated in the discussion of those studies that "...concentrations of fibers in the respirable range encountered in the production industry vary between averages of about 0.03 and 0.2 fibers/ml" (Hill, 1977).

Schneider, in discussion of the mineral wool user industries in Scandinavia (1979), found that home insulation installers and industrial insulation installers had the highest exposures among the user groups, with a few exposures over 1 f/cm^3. He found that optical microscopy was adequate for definition of exposure, which ranged from 0.05 to 3 fibers/cm^3.

The National Institute for Occupational Safety and Health has engaged in several studies that are now being presented. This report presents one such study, and a NIOSH report on one ceiling title productions plant has recently been presented, with information on an epidemiologic study of the workers at that plant (Ness, 1979; Robinson, 1980).

In the investigation reported here, five production sites and six user sites of mineral wool were selected for study, based upon the representativeness of the operations and the conditions of exposure of the workers in those sites. Study methods included breathing-zone air sampling for airborne particulate material (total, fibrous, and respirable) with analyses to determine total and respirable airborne particulate levels (gravimetric); airborne fiber concentrations and fiber size distributions (optical and scanning electron microscopy); and airborne trace metals (atomic absorption). Limited evaluations of worker exposure to carbon monoxide, heat, noise, and miscellaneous other materials were performed in some site surveys. In addition to the environmental evaluation, samples of bulk materials being produced and used were taken for analysis. Analysis included optical microscopic determinations of fiber diameter, determination of bulk sample elemental content by atomic absorption (AA) and x-ray florescence (XRF), elemental analyses of separated fibrous and compact particles by AA and XRF, and elemental analyses of individual particles by x-ray microprobe.

In Tables 1 and 2, we show the general characteristics of the facilities examined.

TABLE 1. MINERAL WOOL PRODUCTION PLANTS SURVEYED

	Plants				
	A	B	C	D	E
Raw materials	Steel mill slag, lead smelter slag Coke, oil, PF resin, asphalt	Steel mill slag, iron ore, "phosphate" slag, coke, PF resin, oil, asphalt	Steel mill slag rock coke maleic acid, oil	Iron smelter slag, dolomite, quartzite, coke, oil	Steel mill slag, dolomite, PF resin, coke, oil
Years of production	28	29	6	20	50
Fiber-forming process	Centrifugal spinner with steam attenuation	Centrifugal spinner with steam attenuation	Dry spinner (Powell process)	Centrifugal spinner with steam attenuation	Centrifugal spinner with air attenuation
Fiber description	Slag wool	Slag wool	Slag wool	Slag wool	Slag wool
Products produced	Batts, blowing wool, and pouring wool	Batts, blowing wool, pouring wool, baled wool	Blowing wool, Baled wool	Ceiling tile	Industrial insulation blocks, blankets, pipe covering
Worker population (Fiber production and maintenance)	100	80	45	15	30
Potential exposures	Fibers, lead fume, H_2S, PF resin, noise	Fibers, combustion products, H_2S, CO, PF resin, noise	Fibers, combustion products, metal fume, maleic acid, noise	Fibers, CO, combustion products noise, general dust	Fibers, noise

TABLE 2. MINERAL WOOL USER FACILITIES SURVEYED

Facility	F	G	H	I	J	K
Product used	Blowing wool (Slag wool)	Blowing wool (Slag wool)	Industrial blankets (Slag wool)	Bulk (slag wool) wool	Fireproofing	Industrial blankets
Application	New house insulation	Addition to existing insulation	Fabrication for shipment	Production of ceiling tiles	Spray application of fibrous fireproofing to structural steel.	Boiler insulation
Processes	Blowing	Blowing	Facing with wire mesh, packing	Mixing wool with slurry, baking, cutting, sanding, painting, packing tiles.	Pneumatic blowing of dry fibrous mix, wetted with spray nozzle as applied.	Facing with wire mesh, application of cement.
Worker population	4-10	4-10	20	60	2	3
Years of use	15	45	50	20	10	15
Potential exposures	Fibers, heat, CO	Fibers, heat, CO, settled house dust.	Fibers	Fibers, clay, paint, noise.	Fibers, dust	Fibers, dust, noise

Although the original report to NIOSH (Fowler, 1978) should be examined for details, we will consider here a few of the points of interest in respect to comparisons with asbestos, and present a summary of the findings.

Figure 4 is a presentation of the 95 percent confidence limits of the geometric means of exposures to fibers, total particulate material, and respirable particulate material in the producer and user facilities surveyed. Also presented there is a comparison of the fiber sizes found in the eleven facilities, by optical microscopy.

Figure 5 compares the fiber concentration found by optical microscopy, with those found by scanning electron microscopy. As can be seen in those two figures, the production workers had substantially lower exposure to all forms of airborne particulate material than did the user workers.

Further, the user workers' exposure was to smaller fibers than was the production workers' exposure. The difference in length can be seen in the lower section of Figure 4, where the sizes of the fibers observed with the optical microscope are shown. The difference in diameter of fibers to which they are exposed between production workers and users is apparently slight. However, as shown in Figure 5, examination of the samples with the scanning electron microscope reveals substantially more fibers than does optical microscopy. The mean concentration by electron microscopy in the 12 samples for which both types of microscopy was applied is nearly four times the mean determined by optical microscopy.

The phenomenon is not universal, however, and two examples are illustrative of the differences in exposure which may appear among users of mineral wool. The first is the installation of "blowing wool" in attics. In this job, two workers are usually employed. One of them opens bags of compressed wool and empties the bags into a hopper from whence the wool is pneumatically conveyed through a hose into the space to be insulated. The second worker directs the blown wool into the space (usually an attic) to ensure adequate depth and uniformity of coverage.

In the second example, the installation of sprayed fireproofing, two workers are also employed. The first empties bagged fireproofing material (a mixture of mineral wool, cement, and proprietary materials) into a hopper/blower very similar to the device used for the installation of the blowing wool. The mixture is also pneumatically conveyed to the second worker via hose. At the point of exit from the hose, however, the blown cement mixture is wetted by a water spray, and the wetted mixture is directed onto beams and other structural members, to which it adheres.

The exposures within the two trades are shown in Table 3.

It is evident that the exposures are different. The blowing wool installers are exposed to substantially more small airborne particulate material of all sorts than the sprayed fireproofing installers, even though the latter are exposed to higher total airborne particulate material.

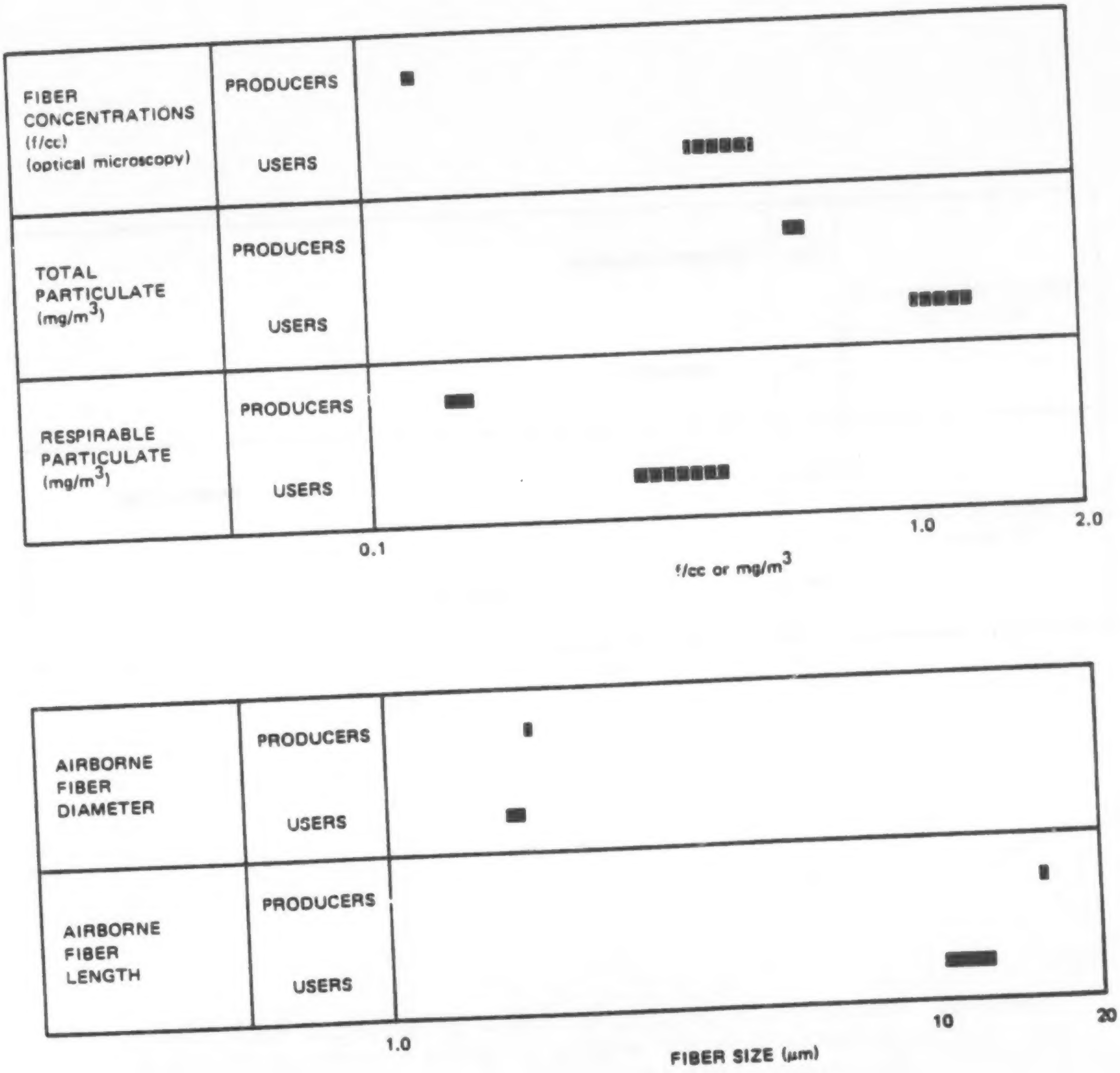


Figure 4. Comparison of exposures of production and user facility workers.

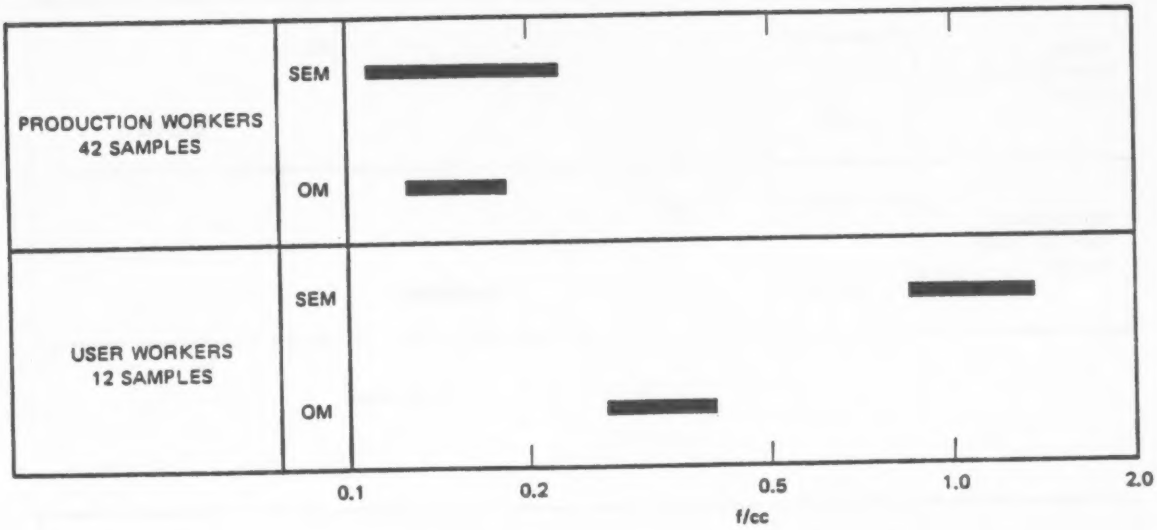


Figure 5. Comparison of confidence limits on geometric mean fiber concentrations for samples examined by scanning electron microscopy (SEM) and optical microscopy (OM).

TABLE 3. COMPARISON OF MEAN EXPOSURES FOR SPRAYED FIREPROOFING AND BLOWN INSULATION

	Sprayed Fireproofing	Blown Insulation
Fibers/cc (O.M.)	0.384 f/cc	0.240 f/cc
Fibers/cc (SEM)	0.217 f/cc	3.09 f/cc
Fiber Diameter (O.M.)	2.4 μm	1.6 μm
Fiber Length (O.M.)	35.3 μm	12.0 μm
Tot. Susp. Part. Matl.	7.461 mg/m^3	2.657 mg/m^3
Respirable Part. Matl.	0.370	2.565 mg/m^3

Our general conclusions were that the production workers surveyed were found to have relatively low exposures to all forms of airborne particulate material, with few exceptions. The user workers had higher but more variable exposures. It was generally not possible to separate exposure categories on the basis of different exposures; there was significant overlap of the confidence limits on mean exposure across the facilities surveyed.

Past exposures in this industry were probably higher than at present, and asbestos exposure was relatively common.

In addition to exposures to airborne particulate material, exposures to excessive noise levels were universal in the cupola areas of the production plants. Heat stress was a potential problem for the installers of blown mineral wool insulation.

Exposures to small diameter (<1.0 μm) fibers were not common, except in the installation of blowing wool. In close installation situations, electron microscopically visible airborne fibers were present in concentrations up to ten times greater than optically visible fibers.

SRI's recommendations were that:

- The exposures of blowing wool installers to small fibers should be evaluated further.
- The noise exposures of cupola operators should be evaluated, and engineering solutions to this problem should be sought.
- The exposure of sprayed fireproofing workers to total airborne particulate material are excessive, and suitable personal respiratory protection should be sought.
- Engineering measures to ameliorate the working conditions of the blowing wool insulation installers should be sought for both the worker in the attic, and the worker emptying bags into the hopper (in the truck).
- Additional old samples should be sought to clearly identify potential past exposures to small diameter fibers.

COMPARISON TO ASBESTOS EXPOSURES

Only two cases are known where mineral wool has been directly substituted for asbestos, and the potential occupational exposures subsequently measured.

Reitze, et al. (1972) evaluated the exposures of sprayed fireproofing installers to airborne asbestos fibers. The material and process used was similar to that used in the installation described above, except that the spray mixture contained substantial quantities of asbestos. The worker emptying bags into the hopper was exposed to concentrations of asbestos fibers ranging from 5-22 fibers/cc (optical microscopically visible fibers > 5 μm), and the nozzle operator was exposed to concentrations between 30-100 fibers/cc. These concentrations were more than 100 times greater than the concentrations found in our study of the workers using a mineral wool based mixture.

Balzer, et al., (1972) investigated the dust-producing potential of five different thermal insulation materials. Of these, one contained ~65 percent asbestos, while another was comprised principally of mineral wool, and was intended as a substitute for the first. The materials were treated by installation methods common in the field, but in a controlled environment. Fiber counts and total dust were measured during each of several operations, including hand sawing, scoring with a circular saw, band sawing, simulation of application, simulation of pounding the insulation into place, and a simulation of tearout of old insulation.

The results are shown in Table 4.

The potential exposures to fibers from the product containing mineral wool are substantially (10-40 times) lower than from the asbestos-containing product. Total particulate material exposures varied. In some cases, the exposure was higher, and in some cases lower, for the mineral wool product as compared to the asbestos product.

From these two cases, it seems reasonable to tentatively conclude that total exposure to fibrous particulate material can be reduced by the substitution of mineral wool for asbestos in some products. Each case must be judged individually, however, and the suitability of any proposed substitute must be carefully guaged. Asbestos has been used in many widely-variant products because of its unique physical characteristics. The wholesale-enforced substitution of mineral wool (or any other material) for asbestos may have serious economic and technical repercussions. The entire life-cycle of each product containing asbestos must be investigated before a decision to substitute is made. The most suitable substitution must then be selected, based upon the uses and available production technology for the specific product under consideration.

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TABLE 4. COMPAIRSON OF ASBESTOS AND MINERAL WOOL CONTAINING INSULATION, AVERAGE DUST GENERATION
(Source: Balzer, et al., 1972)

	Total Particulate Material (mg/m^3)		Fiber Count (F/cc)	
OPERATION	A	B	A	B
Hand Sawing	12.6	3.9	57.3	1.7
Band Sawing	89.8	58.6	376.2	23.1
Scoring	159.8	345.8	2629.7	63.2
Application	7.9	3.1	74.2	0.9
Pounding	2.3	3.4	--	--
Tearout	26.4	62.9	268.4	26.6

A - Asbestos
B - Mineral Wool

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DISCUSSION ON MINERAL WOOL

QUESTION (Mr. Dickinson): Arsenic occurs naturally with lead and copper. Did you say that 30 percent of the rock wool made in the country is made using copper slag?

ANSWER (Mr. Fowler): I said that approximately 70 percent is made using steel mill slag and that the remainder is made using lead smelter slag, copper smelter slag, iron smelter slag and natural rock.

QUESTION (Mr. Dickinson): Okay, but in essence some of it is made using either lead or copper melting slag?

ANSWER (Mr. Fowler): That is correct.

QUESTION (Mr. Dickinson): Since arsenic occurs naturally in nature with those materials did you do any sampling in the areas where that kind of slag was being used to see what kind of exposure was being given perhaps to the workers in the way of arsenic as opposed to particulates? If we are looking at what the problems are in using substitute materials for asbestos this might be something that we ought to be considering.

ANSWER (Mr. Fowler): I did not look particularly at arsenic. We did look at lead exposures. We found one single exposure to lead that was above the then current OSHA standard. That was in a single individual who was using personal respiratory protection as well. So that his actual exposure would have been substantially less than that measured. Other than that we did not find excessive exposures to lead.

MORTALITY PATTERNS OF ROCK AND SLAG MINERAL WOOL PRODUCTION WORKERS

EPIDEMIOLOGIC AND ENVIRONMENTAL STUDY

by

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ABSTRACT

An epidemiologic and environmental study of rock and slag mineral wool production workers was undertaken at a plant which has been in operation since the early 1900's. Size characteristics of fibers produced by each process at the plant and industrial hygiene survey data were used to evaluate current and past exposures. These data suggest that the average historical airborne fiber concentration probably did not exceed 2.5 fibers/cc before 1935 and 1.0 fiber/cc after 1935. A retrospective cohort mortality study was designed to assess mortality patterns. Detailed occupational histories were compiled on all plant employees. All jobs in the plant were assigned to one of eight potential exposure categories to assess the extent of severity of mineral wool exposure and the effect of other significant exposures on employee mortality. Findings included an increase in the number of deaths due to digestive system cancer and nonmalignant respiratory disease among workers who had greater than 30 years exposure to mineral wool or who had survived 30 years since their first exposure to mineral wool. These findings corroborate those of the Thermal Insulation Manufacturers' mortality study of men employed in four mineral wool plants (Enterline and Marsh, 1979).

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*Presented by Cynthia F. Robinson, M.S. Paper is being prepared for publication elsewhere.

DISCUSSION ON ROCK AND SLAG MINERAL WOOL

QUESTION (Mr. Shaines): Did you say that nothing in the data showed a significantly greater death rate from the slag workers versus the county workers?

ANSWER (Ms. Robinson): There was no statistically significant excess of deaths.

QUESTION (Mr. Shaines): That is right. From that you conclude that there was an increase in deaths?

ANSWER (Ms. Robinson): There was an increase of observed deaths over what was expected.

QUESTION (Mr. Shaines): If it is not significant then it is not an increase. That is the meaning of the word.

ANSWER (Ms. Robinson): There were more deaths than what was expected.

REMARK (Mr. Shaines): Not significant.

REMARK (Mr. Wright): It was an increase but it was not statistically significant. I think that is the way to say it.

REMARK (Mr. Shaines): That is right.

REMARK (Mr. Wright): That does not mean it is not an increase.

REMARK (Mr. Shaines): I will go through the words again. The probability was that there was not an increase. That is what the word significant means.

REMARK (Mr. Wright): It means the increase was not significant at the 0.05 level. That does not mean the probability was that there was no increase whatsoever. All it means is the chances are less than 1 out of 20.

REMARK (Mr. Shaines): That is right. The odds are 20 to 1 that there was not an increase.

REMARK (Mr. Wright): No, just the opposite. In the 5 percent level the odds are 20 to 1 that there is not an increase if it is not significant. That is what the odds are.

REMARK (Dr. Bernstein): I would assume that your Null hypothesis is that there is probably no increase. If that is the case, there is a 20 to 1 probability that your Null hypothesis is not true; therefore it is a 20 to 1 probability that there is an increase.

REMARK (Ms. Robinson): If I can restate it again. I would say the odds are that this increase could have been seen by chance alone, however, there were more deaths occurring than was expected on the basis of our comparison population.

REMARK (Unidentified): There were increases in several categories of cancer and in almost all of these cases there was a latency period effect present at 30 years. I think if you took the information on increases in about three different types of cancer, essentially all of them occurring at 30 years, and combined them by nonparametric techniques, you would have no problem showing significance.

REMARK (Mr. Wright): I am from the Steelworkers Union.

Just a quick comment about statistical significance. Two things would be useful in these types of reports: first is the 95 percent confidence interval around the results, and second is that even though it is useful to say this finding was or was not significant at the 0.05 level, it might be interesting to know at what level it was significant.

I would suspect for some of these numbers we are talking about maybe the 0.1 or 0.2 level? Now no scientist in his or her right mind would say that means those results are statistically significant, but they might have meaning to a worker. For example, if a work place has a result that is significant at the 0.1 level, the professional might say that is not a statistically significant result and tests have not proven that this stuff causes cancer or fibrotic lung disease. But a worker looking at that result, if he or she understood the statistic, might conclude quite correctly that the chances are nine to one that there is a problem. That is what it means to say it is significant at the 0.1 level, nine to one that there is a problem. It is not enough to publish in a scientific paper how we have proven a problem exists but it sure is enough to worry me. That is what those results mean to me.

QUESTION (Mr. Castleman): I gather from what you said that a small amount of asbestos was used, at least in that plant, and there was a question about the previous job histories of the workers. If you could get pathological material or autopsy records or possibly something even more recent from someone in this group who had died, you could see the state of the tissues and learn a little bit more about what was going on there.

ANSWER (Ms. Robinson): Yes, that is a good suggestion. Unfortunately, there are very few individuals involved in the study and the rate of obtaining that kind of information and also tissue samples, which would be needed, is very, very low. It has been less than 50 percent in our previous attempts. However, I think we are attempting to do that.

QUESTION (Mr. Castlemen): What about obtaining chest x-rays from the individuals who are in bad shape from nonmalignant respiratory disease?

ANSWER (Ms. Robinson): I do not know about that.

REMARK (Dr. Konzen): I am from TIMA.

I think epidemiology is a very strong tool. We use it a great deal, as I pointed out in my talk. I think it is extremely important to remember that we are talking about one plant with a population of about 700 people that is being studied.

As Ms. Robinson mentioned, the Thermal Insulation Manufacturers Association is carrying out a study that encompasses not only mineral wool workers but fibrous glass workers. The first part of the study reported little evidence of disease from a malignant or a nonmalignant standpoint. This was a preliminary report and a further report, which is expected the latter part of this year, will look at many more of these mineral wool workers.

The other thing that is important to to keep in mind is the study that I mentioned this afternoon. It was a larger study on fibrous glass workers. In the study we found no excess of either malignant or nonmalignant disease in any category and the overall disease rate was quite low. This study will be made available to the regulatory agencies for review.

I think before we get excited about one plant we should use epidemiology where it is strongest and that is in the largest population that we can involve.

REMARK (Ms. Robinson): I would like to respond to the previous person who asked a question because he did imply that the use of asbestos at this plant was considerable. In fact, that was not the case as we understand it.

REMARK (Mr. Cooper): I am from Berkeley.

I, having been involved in a number of epidemiologic studies myself, appreciate Ms. Robinson's dilemma and I think the final conclusions that she came to were reasonable conclusions to arrive at from this material. There are other things to consider and the question of statistical significance and ideologic significance and social significance are interrelated but different questions, and it would be improper to say there was a nine to one chance of someone getting a digestive cancer, even a nine to one chance of there being a problem. The difficulty here is you have a relatively small increased risk and a relatively small population and that combination leads to data that are very difficult to use to establish statistical significance.

I think it would be wrong to combine into one analysis the respiratory tract cancers and the nonmalignant respiratory diseases with the digestive cancers to show significance. The respiratory disease cancers are quite a different problem. The interfering effects of smoking are so overriding in many industrial populations that they cannot easily explain the difference you see in this population. Secondly, they tend to coincide with the duration of employment so you tend to get a spurious appearance of latency. I think this would be incorrect.

I think the nonsignificant and rather small increase in digestive tract cancer is something that I would regard with concern and something that needs further study. We are dealing with raw materials that may potentially contain carcinogens. So, I feel the very guarded conclusions that came from NIOSH were warrented conclusions.

REMARK (Ms. Robinson): It is hoped that futher follow-up of this study as well as the others will produce more definitive conclusions.

REMARK (Mr. Scheckler): I am from TIMA.

I had an opportunity to review some of the records at that particular plant. The one thing I found missing in your presentation was the fact that there was an interchange of employees between the studied plant and an adjacent plant 40 miles away owned by the same company. That interchange of personnel back and forth did not show on the records. Now I cannot tell you the materials manufactured at the other plant. That would have to be reinvestigated. But this exchange of people did take place quite often.

INDUSTRIAL HYGIENE AND TOXICOLOGY ASPECTS OF 3M NEXTEL® 312 CERAMIC FIBERS

by

Mr. Robert S. Larsen and Mr. William McCormick*
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ABSTRACT

NEXTEL® 312 Ceramic Fibers are continuous filaments. Individual filaments are comprised of metal oxides, are transparent, smooth and round, and are microcrystalline in structure. The nominal diameter of the continuous filaments is 11 microns. The primary health effect associated with NEXTEL® 312 Ceramic Fibers is skin irritation. However, tolerance to the irritation develops after several days of handling. Irritation studies and worker exposure data are discussed. Airborne fiber concentrations measured in a 3M manufacturing facility and in a customer facility involving several operations have been shown to be extremely low (maximum of 0.0005 fibers/cc air). The length of the airborne fiber is quite variable (20-6,200 microns) and the diameter is generally greater than 10 microns. Airborne fibers are thus classified as being essentially nonrespirable.

Toxicity studies are currently under way to evaluate the fibrogenic potential of NEXTEL® fiber. Some comparisons to asbestos and fiberglass are made. The inhalation hazard associated with NEXTEL® 312 Ceramic Fibers is judged to be minimal.

NEXTEL® 312, manufactured by 3M is a ceramic textile fiber. The 11 micron diameter continuous filaments have a variety of properties including low thermal conductivity, high temperature resistance, and electrical non-conductivity. Products made from this fiber include fabrics, tapes, sleeving, and cordage (Figure 0).

The first portion of this presentation will be an introduction to the fibers and their toxicity. Secondly, the results of industrial hygiene studies will be discussed.

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* Presented by Mr. Robert S. Larsen.

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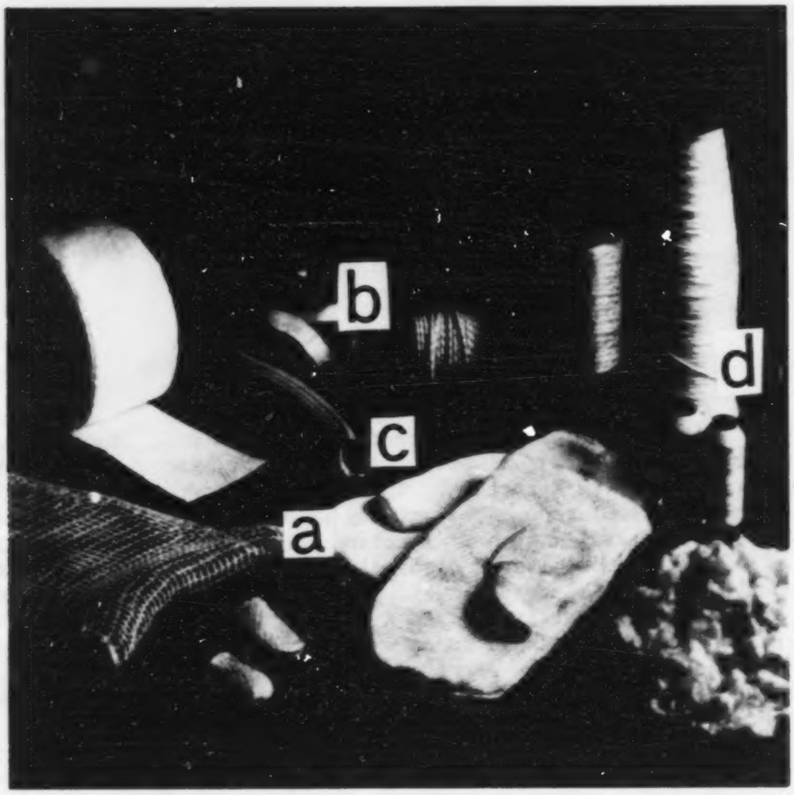

Figure "0" Products made with NEXTEL^R 312

Ceramic Fibers

a. Fabrics
b. Tapes
c. Sleeving
d. Cordage

NEXTEL FIBER AND TOXICITY

Figure 1

The uniform roundness of the fiber is apparent in this scanning electron microscope photograph showing a cross section of three fractured filaments at 6000 X magnification.

Figure 2

As you can see in this figure, the round fibers have a uniform smoothness.

Figure 3

In the next figure, a 100 X magnification photograph shows the uniform, transparent quality of the filaments.

Figure 4

The typical NEXTEL® 312 ceramic fiber is comprised of three inorganic oxides in the following percentages:

Aluminum oxide	62 percent
Boron oxide	14 percent
Silicon dioxide	24 percent

(Figure 4)

In processing, the fiber attains a microcrystalline structure.

Figure 5

As you can see, the micrograin crystals of the NEXTEL® fiber shown in the top photomicrograph are approximately 0.01 to 0.02 microns in length. This can be compared to other ceramic materials having much larger "fine-grain" ceramic crystals (seen in the middle photograph) and an amorphous form of noncrystalline ceramic structure seen in the bottom photograph.

NEXTEL® ceramic fibers are manufactured to be an 11 micron diameter continuous filament. 3M began selling ceramic fibers commercially in 1977. As a result, there has been insufficient time to develop a history of any possible chronic human health effects. Since the fibers are of such large diameter, the inhalation hazard associated with their manufacture and use is believed to be quite low. Industrial hygiene surveys conducted in both manufacturing and user facilities have confirmed this and will be expanded upon later.

The fiber has been assessed for its skin and eye irritation potential in the rabbit.

Table 1

This table shows the results of the primary skin irritation study conducted on the fiber. The study conducted was a conventional Draize primary skin irritation study[1] using the Federal Hazardous Substances Act protocol

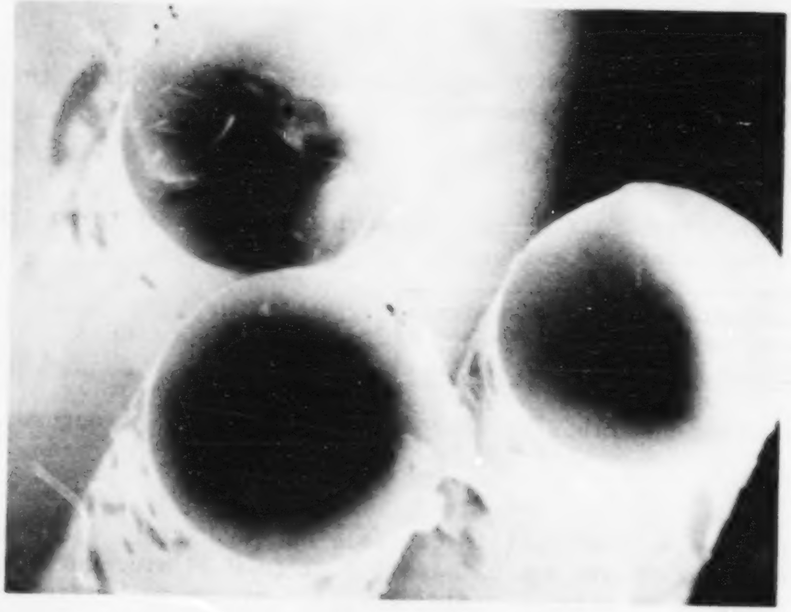

Figure 1 Roundness of the fiber (6000 X)

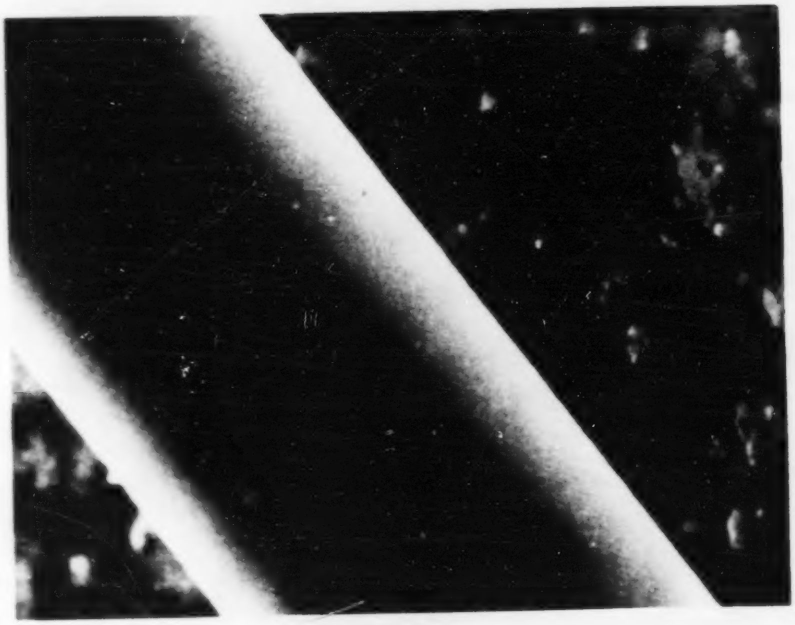

Figure 2 Smoothness of the fiber surface

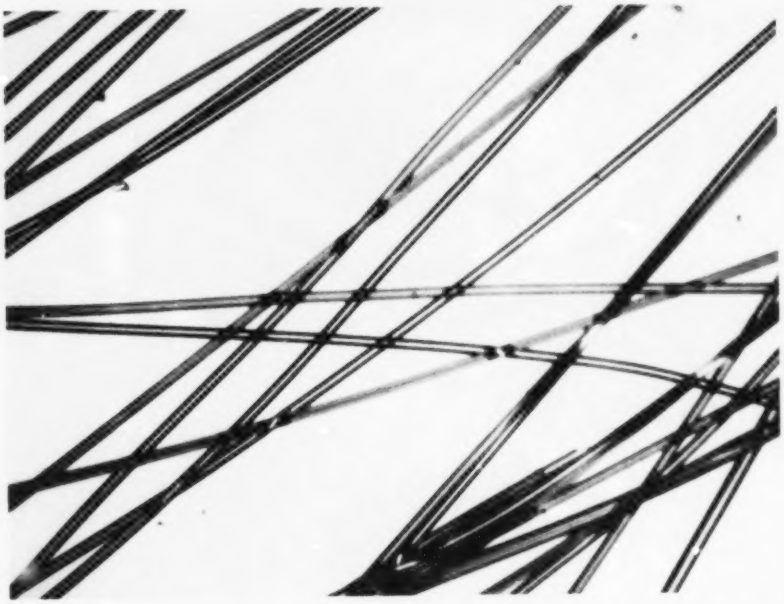

Figure 3 Transparent Quality of the Filaments

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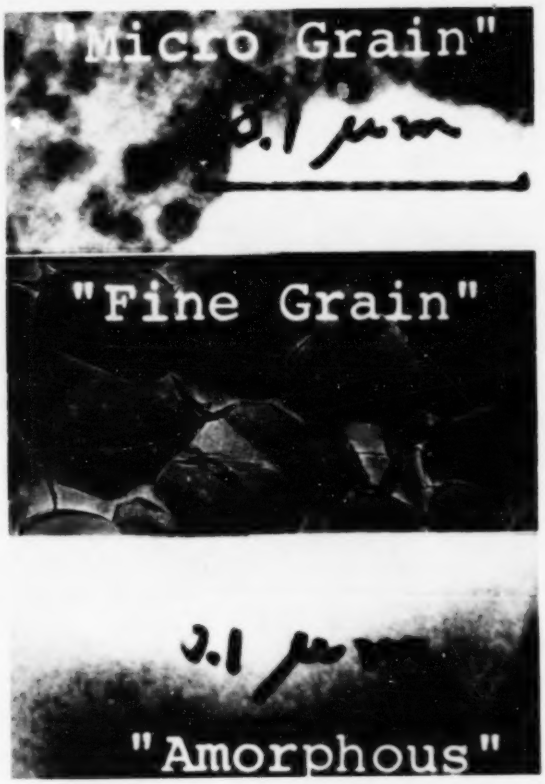
"Micro Grain"
0.1 μm
"Fine Grain"
0.1 μm
"Amorphous"

Figure 5 Contrast between three ceramic structures

"Micrograin" - NEXTEL^R 312
"Fine Grain" - Aluminum Oxide
"Amorphous" - Fibrous Glass

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TABLE 1. NEXTEL® 312 CERAMIC FIBER PRIMARY SKIN IRRITATION

	Reading (hours)	Rabbit number						Average
		1	2	3	4	5	6	
Erythema and Eschar Formation								
Intact Skin	24	1	1	0	0	1	0	0.50
Intact Skin	72	1	0	0	0	0	0	0.17
Abraded Skin	24	1	1	0	1	1	0	0.67
Abraded Skin	72	1	0	0	0	1	0	0.33
			Subtotal					1.67
Edema Formation								
Intact Skin	24	0	0	0	0	0	0	0.00
Intact Skin	72	0	0	0	0	0	0	0.00
Abraded Skin	24	0	0	0	0	0	0	0.00
Abraded Skin	72	0	0	0	0	0	0	0.00
			Subtotal					0.00
			Total					1.67

Primary Irritation Score: 1.67 ÷ 4 = 0.42

and scoring method.[2] A 0.5 gram sample of the test material was placed on intact and abraded skin test sites on 6 albino rabbits for a period of 24 hours. After removal of the occluded patch, the sites were scored for erythema and edema formation. At 3 of 6 intact sites and 4 of 6 abraded sites, slight reddening was observed at the 24 hour reading. At intact sites the score was 0.5. At the abraded sites the score was 0.67. By the 72 hour reading the irritation was reduced to 0.17 at the intact sites and 0.33 at the abraded sites. The total primary skin irritation score was 0.42. This classifies the fiber as minimally irritating dermally.

These data are confirmed in plant experience. People initially working with ceramic fibers tend to experience a low grade irritation response. The response fades within several days of working with the fiber. The experience is similar to the fiberglass skin reactions noted by several researchers (Sulzberger, et al, and Erwin).[3,4] The eye irritation results showed that the ceramic fiber failed to elicit any signs of irritation in any animal on study. Again, plant experience indicates eye irritation problems in persons handling ceramic fibers are quite rare.

The acute skin and eye data on NEXTEL® fibers indicate a relatively low hazard in the handling and processing of the product. However, of primary concern is the possible chronic effects of inhalation exposure to the fiber. As I mentioned earlier, NEXTEL® ceramic fibers are, in the realm of fiber dimensions, quite large. Their diameters are in the 11 micron range and the lengths are essentially continuous. Short fibers are created as the result of breakage of the continuous filament. Breakage is of low enough incidence in manufacture and usage to preclude a significant build up of airborne fibers. Many of the fibers that are created are large enough to settle out of the air rather than remain suspended. Therefore, they are unavailable for inhalation. Additionally, longitudinal fracturing, a process which commonly occurs with asbestos fibers, has not been encountered with NEXTEL® ceramic fibers.

Because of the above considerations, 3M has not conducted any fiber inhalation studies, acute or chronic. Fibers of large diameter and length are considered nonrespirable. If inhaled they would be expected to be intercepted in the nasopharyngeal region of the respiratory tract and eliminated through normal clearance mechanisms (Timbrell, Harris and Fraser).[5,6] Research conducted by Stanton, Timbrell, Wagner,[7,5,8] and others indicate there is a relationship between fiber geometry and an adverse biological response. It is believed that for a given fiber diameter the longer the fiber the greater the likelihood of adverse biological response. However, the fiber diameter must be less than 5 microns.

Although current information suggests exposure to NEXTEL® fibers is extremely low, 3M is beginning an intratracheal insufflation study to determine the fibrogenic potential of the fiber.

Additionally, and more importantly, the industrial hygiene surveys conducted by 3M indicate air concentrations of ceramic fibers to be very low, thus diminishing the concern of inhalation exposure hazard.

INDUSTRIAL HYGIENE ASPECTS

Table 2

Industrial hygiene studies have been conducted at a 3M production facility and customer facility in order to determine the concentrations (fibers/cc) or airborne NEXTEL® 312 ceramic fibers to which employees are exposed in addition to the physical characteristics (length, diameter) of the fiber. I will discuss sampling procedures, analytical methods, results of the studies and a comparison of the results with existing OSHA standards and NIOSH proposals for other fiber types.

Table 3 - Sampling

Personal and general area air samples were collected on open-faced type AA Millipore filters. Sampling times were up to 60 minutes in duration and dependent upon the particular operation being monitored.

Table 4 - Analysis

The whole filter was counted using an Ortholux microscope. The ceramic fibers are relatively easy to identify on the filter. However, it is possible that other airborne fibers may have been counted in addition to the ceramic fibers.

Table 5 - Results

An industrial hygiene survey was conducted in a textile operation using the fibers. Airborne ceramic fiber concentrations found in the customer facility are judged to be very low for the various processes monitored. The mean airborne concentration for all processes monitored was 0.00004 fibers/cc of air. The airborne fibers may be characterized as being quite long with a correspondingly large diameter. The mean length was 261 microns and the mean diameter 10 microns. The airborne fibers in the textile plant may be classified as being nonrespirable. The inhalation for 3M customers handling the fibers is judged to be minimal.

Table 6

Much the same results were found in 3M's ceramic fiber production facility. However, the length and diameter of the airborne fibers in 3M's production facility are quite a bit larger than the fibers found in the customer facility. This is due primarily to the inherent nature of the manufacturing process which results in the generation of larger airborne ceramic fibers. The mean airborne concentration was found to be 0.0001 fibers/cc of air. The mean airborne fiber length was 986 microns and mean diameter 25.8 microns.

Table 7 - Comparison of Results with Standards and Proposals

None of the airborne ceramic fibers found in these studies would be considered countable under the existing OSHA asbestos standard and proposed

TABLE 2. INDUSTRIAL HYGIENE STUDIES ASSOCIATED WITH AIRBORNE 3M NEXTEL® 312 CERAMIC FIBERS

I. Sampling

II. Analysis

III. Results

    A. Customer Facility

    B. 3M Production Facility

IV. Comparison of Results with OSHA Standards and NIOSH Proposal for Other Types of Fibers

TABLE 3. SAMPLING

1. AA Millipore Filter (open-faced)
2. Flowrate - 2.5 LPM

   Duration - up to 60 minutes
3. Personal and area samples

TABLE 4. ANALYSIS

1. Ortholux Microscope
    A. Count whole filter
    B. Use mechanical stage
    C. Use micrometer eyepiece
2. Ceramic fibers are relatively easy to identify but may also be counting other airborne fibers on the filter.

TABLE 5. RESULTS - CUSTOMER FACILITY PERSONAL SAMPLES

Operations	Concentration (No. fibers/cc air)	No. fibers on filter	Fiber sizes (μ)	
			Length	Diameter
1. Serving	0.00004	6	120	13.5
			192	8.1
			216	8.1
			264	8.1
			300	10.8
			300	10.8
2. Serving	0.00001	2	108	10.8
			792	10.8
3. Core Winding	0.000007	1	120	8.1
4. Weaving	0.00005	8	151	10.8
			180	10.8
			215	10.8
			229	10.8
			264	8.1
			300	8.1
			324	9.5
			360	10.8
Mean	0.00004	4.25	261	10

TABLE 6. RESULTS - 3M PRODUCTION FACILITY

Sample description	Concentration range (No. fibers/cc air)	Range of No. fibers on filter	Range of fiber sizes (μ) Length	Range of fiber sizes (μ) Diameter
Area samples taken in fired fiber locations	0-0.0005	0-14	20-6200	9.3-37
Mean	0.0001	4.6	986	25.8

TABLE 7. OSHA STANDARD AND NIOSH PROPOSAL

Standard or proposal	No. fibers/cc air	Fiber size (μ) Length	Fiber size (μ) Diameter
OSHA - Asbestos	2 (TWA)	>5	*
NIOSH - Fiberglass	3 (TWA)	≥10	≤3.5
NEXTEL® Ceramic Fibers-			
3M Mean	0.0001	986	25.8
Customer Mean	0.00004	261	10

*An asbestos fiber is defined as a particulate form of asbestos, longer than 5μ, with a length to diameter ratio of at least 3 to 1 and a maximum of 5μ.

NIOSH Fiberglass Recommended Standard.[9] Even if the fibers were considered countable, the airborne concentrations which were detected are well within the concentration limits set forth in the Asbestos Standards and Fiberglass proposal.

In conclusion NEXTEL® 312 ceramic fibers are continuous filament large diameter fibers that present a low inhalation hazard in manufacture and processing. They represent a relatively safe alternative to asbestos in the thermal protection fabric area.

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DISCUSSION ON CERAMIC FIBERS

QUESTION (Dr. Cooper): If there is no question on this particular paper I would like to clarify my comments on the previous paper, if this is in order.

ANSWER (Chairman Rowe): That is fine.

REMARK (Dr. Cooper): There are some individuals here who seem to have the impression that I said that I felt the NIOSH study showed that mineral wool caused an increase of digestive cancer. This was not what I intended to convey at all. The point I meant to make was that I agreed with the conclusions of Ms. Robinson that the study was inconclusive and that this was an area that certainly deserved further study.

TOXICOLOGY OF ARAMID FIBERS

by

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ABSTRACT

Du Pont's two high performance aramid fibers, Kevlar® and Nomex®, are functionally qualified and cost-effective as asbestos replacements in many industrial applications. Both fibers are based on aromatic polyamides, which confer excellent high temperature stability and, with Kevlar®, outstanding strength, stiffness and frictional properties over a wide temperature range. Several trade programs are under way to replace asbestos in friction products, gasketing, plastic reinforcement, thermal insulation and protective clothing.

Neither Nomex® nor Kevlar® fibers produce allergenic reactions on skin contact. Initial inhalation and/or intratracheal insufflation studies of fibers of Nomex® and polymeric dust of Kevlar® in rats showed that both materials produced only minimal tissue reaction (nature of reaction varied with particle size and shape) in the lungs with no collagen formation. These observations appear to meet the criteria of a biologically inert dust, namely: (a) absence of collagen formation; (b) potential reversibility of the lesions; and (c) maintenance of normal architecture of the air spaces.

Results of these preliminary studies indicate that the use of aramid fibers to replace asbestos poses no significant health hazard to persons processing aramids or to the user of the final product. More extensive toxicological studies are planned to confirm these results.

INTRODUCTION

Du Pont's two aramid fibers, Nomex® and Kevlar®, are rapidly gaining acceptance as commercially viable replacements for asbestos in a number of applications such as insulation, flame barriers, thermal protective clothing, and particularly, friction products.

Key to the functional acceptability of Nomex® and Kevlar® is their chemical structure. Both are based on aromatic polyamides and differ only in the substitution position on the aromatic rings. These fibers are inherently flame

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resistant and do not melt. In fact, neither will sustain combustion in a normal atmosphere when the ignition source is removed. Thermal and oxidative stabilities are also outstanding, so that each can withstand long-term in-use exposure at very high temperatures for organic fibers.

Nomex® and Kevlar® fibers have been sold commercially for about 15 and 8 years respectively. To date, industry has consumed millions of pounds of each material with no known health hazards from the fibers either in manufacture or use.

I will turn now to a description of the procedures and results of our toxicological testing of Nomex® and Kevlar®.

PROCEDURES AND RESULTS

Human contact with these fibers is most likely to be by the dermal route along with potential respiratory exposure, so we have concentrated our efforts on these exposure routes. Both Nomex® and Kevlar® have been studied to evaluate skin irritancy and skin sensitization potential in animals and man. These studies involved primarily human volunteer panels in which from 100 to 200 individuals per study were patch tested. They showed no potential for skin sensitization and only minimal chance for skin irritation to develop following dermal contact with fabrics of either Nomex® or Kevlar® . Because these fibers, especially Kevlar® , are stiff, potential exists for causing abrasive skin irritation under restrictive contact.

To evaluate the potential problems that might be associated with respiratory exposure to Nomex® , the long-term lung response to dust generated by shredding and grinding a paper of Nomex® aramid was studied. Two and one-half milligrams of the material, suspended in physiological saline solution, was instilled into the trachea of rats. The test material in the lung appeared as acicular, oblong, or rod-shaped particles varying in size from 2-100u in length and 2-30u in diameter. Tissue response was measured by evaluating the respiratory tract histopathologically. Groups of rats were examined 2 and 7 days, 3 and 6 months, and 1 and 2 years following treatment.

No signs of an adverse response to the test substance were seen - these included observations for clinical signs, growth as measured by body weight data, and mortality patterns. At each of the sacrifice intervals, the test material was observed microscopically in the lung tissue. However, the nonspecific tissue response was characteristic of that experienced generally with foreign particles in the lung; that is, an initial transitory acute inflammatory response followed by foreign body granuloma formation. The later response was provoked by the larger, non-respirable sized dust particles in the range of 30 X 100u. The smaller, respirable sized particles, <10u, produced only a negligible dust cell reaction similar to that seen with nuisance particulates. During the post-exposure recovery period, most of the dust laden macrophages were eliminated from the lung within three months.

These mild tissue reactions became less obvious as the post-exposure time increased and the exposed lungs returned to essentially normal architecture without formation of collagenized fibrosis two years after exposure. This experiment in rats intratracheally insufflated with fibrous dust of Nomex® did not show any progressive pulmonary fibrosis, collagenization or clinical bronchopulmonary distress.

We next concentrated our efforts on Kevlar® since it is a rather unique fiber in that it has a greater tendency than most fibers to fracture along the fiber axis. In some textile processing operations it has a propensity to form some small fibrous particles. That characteristic, along with Du Pont's interest in very short, highly fibrillated pulp forms as an asbestos replacement, has caused us to center our concern on these small particles. We started with dust converted from raw polymer, rather than dust converted from fiber, since we could not isolate enough fiber dust from textile processing operations for our tests.

The polymer dust tested contained a low, but undetermined proportion of fibrous particles considered to be in the respirable range, <1.5u in diameter and between 5 and 60u in length. Larger, non-respirable particles ranged up to 150u in diameter. Particle shapes were variable. Chemically, this material is identical to fiber particulates. In our first study, the acute inhalation toxicity potential was measured by generating the highest dust concentration possible and by exposing rats to this atmosphere for 4 hours. Concentrations in the exposure chamber were analyzed gravimetrically and averaged 150 mg/m^3. Only minor signs of a response, such as decreased activity, were seen during the exposure period. No signs of a response were seen post-exposure. The acute lethal concentration in rats is thus in excess of 150 mg/m^3. However, as indicated above, only a small percentage of the dust was of respirable size.

Since we were concerned with not only the effects of a single massive exposure but also with potential cumulative effects following a series of exposures, a subacute inhalation study of the Kevlar® polymer dust followed. In this experiment, rats were exposed to 130 mg polymer dust per m^3 air for 4 hours per day, 5 days per week for each of 2 successive weeks. Observations of the rats for clinical response to the dust were made daily. A reference group of control rats exposed to houseline air only was run concurrently. Immediately following the last exposure, half of each group, test and control, was sacrificed and each rat was given a complete gross pathological examination including weights of the lungs and other major organs. Microscopic examinations of 21 tissues/organs were conducted. The remaining rats were sacrificed and examined similarly following a 14-day recovery period.

During the exposures, test rats were slightly less active and gained somewhat less weight than did the controls. This was not seen during the recovery period. Gross pathological examination and organ weight data revealed no treatment-related differences.

Microscopically, rats examined after the 10th exposure showed numerous macrophages throughout the lung tissue. At the end of the recovery period, these macrophages decreased in number and tended to form discrete clusters indicating a typical non-specific response to foreign particles in the lung. All other tissues and organs examined either immediately following exposure or after the recovery period were free of treatment-related changes.

Repeated exposure of rats to 130 mg of polymer dust/m^3 produced only mild clinical symptoms during, but not after, exposure. A slight change was produced in the lung, manifested by phagocytosis of the test material. This typical dust-call reaction was also observed following the 14-day recovery period.

To evaluate the tissue response on a long-term basis, the next study involved intratracheal instillation of 25 mg of Kevlar® polymer dust in physiological saline solution into rats. A group of control rats treated with saline alone was included. Rats were then held without further treatment and were sacrificed at 2, 7, and 49 days and 3, 6, 12 and 21 months after treatment.

At each sacrifice, a complete gross pathologic examination including weights of the major organs was conducted. Histopathologic examination of the respiratory tract was also conducted.

Over the 21-month test period, mortality rates, clinical observations, and gross autopsy results were similar for test and control groups.

Following instillation, particles could be detected in lung tissue, the large particles, approximately 100-150u in diameter, mainly in terminal bronchioles, smaller-sized particles, approximately 5u in size, in alveolar ducts. The initial, non-specific inflammatory response subsided within 1 week and foreign body granulomas containing the larger non-respirable dust particles were seen in later sacrifices. Negligible amounts of collagen were present around the dust-laden large granulomas. All tissue responses to the dust particles decreased with increasing time post-treatment.

From this experiment, we conclude that the intratracheal instillation of respirable and non-respirable-sized polymer dust particles of Kevlar® produced only a non-specific dust cell reaction similar to that seen with inert dusts. The material is considered non-fibrogenic and only mildly irritating since the pulmonary lesions showed marked reversibility, no collagen formation associated with the respirable-sized dust particles, and only the large, non-respirable dust particles were able to produce foreign body granulomas.

We are currently engaged in a program to evaluate fibrous particles derived from ground Kevlar® aramid fiber (pulp), for which we expect to find wide use as an asbestos replacement. This includes a subacute inhalation study with extended recovery times and insufflation with the dust of fibrous particles. The need for other work, including the possibility of a lifetime inhalation study, will be evaluated as the results of the currently planned studies become available.

COMMENTARY

These toxicological test results give us confidence that neither Nomex® nor Kevlar® poses a significant health hazard to our workers, to those who process the fiber into asbestos replacement products, or to the end users of those products. This position is supported by the safe use of millions of pounds of aramid fibers in a range of other end uses over many years and good medical surveillance of our employees who have handled them. While the test conditions utilized do not simulate directly real-life exposures to these products, we believe that, if anything, the tests exaggerate use conditions. Our toxicological testing program is continuing in order to document our hazard assessment and to provide added support as the range of end uses increases.

DISCUSSION ON ARAMID FIBERS

QUESTION (Mr. Spitzer): I am from the Consumer Product Safety Commission.

Three quick technical questions: (1) how many animals were in each group that you used; (2) what about the spontaneous tumors in each group; and (3) have you done any transmission electron microscopy, and specifically looked at the type 1 to type 2 cell ratio in the lung tissue?

ANSWER (Dr. Reinhardt): In response to the first question, there were approximately 40 animals in each group and 5 were sacrificed at each of the intervals, holding the remaining ones until the end. Your last question about the electron microscopy, that has not been done. And your second question about tumor incidence will be answered by our pathologist who reads these slides, Dr. Lee.

ANSWER (Dr. Lee): Each period we sacrificed five rats. At the end of 21 months there were about five rats left. Therefore, it is almost impossible to check the carcinogenicity with that small a number of animals. So we cannot answer that question.

QUESTION (Dr. Lewinsohn): I am from Raybestos-Manhattan.

With regard to the question of carcinogenicity, I assume that you will be conducting survival type experiments to determine whether there is an incidence of carcinogenicity in these animals. And I wonder have you considered the instillation of fiber into the pleural cavity directly, in other words, the Stanton type experiment?

ANSWER (Dr. Reinhardt): As far as answering your first question, yes, definitely. In particularly the longer term type studies that we do, the animals will be held for their lifetime to evaluate any carcinogenic potential. In elaborating a bit on Dr. Lee's response, even though the numbers of animals was relatively small at the end of the study so that it would make it difficult to evaluate with great assurance the absence of any carcinogenic potential, there was no evidence that this was a problem based on the studies that we have done up to this point. Right at the moment we do not have any plans to carry out pleural instillation. We feel that the insufflation studies and the more physiological inhalation studies would be appropriate.

REMARK (Dr. Cooper): I am from Berkeley.

Several years ago, Pimental, Avila, and Villar, in Portugal, described pulmonary reactions in a variety of industries where more or less insoluble and durable dust was inhaled. I looked into this briefly and it appeared that there was a pattern of exaggerated granulomatous response in a number of individuals, including individuals who had worked with a number of the synthetic textile fibers. I have not heard anything about this lately, but it is suggested with the type of response that you see in your animals that an occasional individual might have an exaggerated granulomatous response to the deposition, inhalation or retention of some of these dusts, which simulates a sarcoid-like reaction. I just wondered if there have been any human experiences in the United States that would suggest that occasionally individuals would have this. It is not a fibrosis, it is not a pneumoconiosis, but it could create an impression that you are getting a pneumoconiosis when it really is probably a highly individualized response. I wonder if you would comment on this general topic.

ANSWER (Dr. Reinhardt): I am also familiar with the Portugal study. To the best of my knowledge I do not know of any actual studies where there are autopsy findings correlating a response such as you describe, this granulomatous response, with the exposure to specific fibers. In the Portugal study, I think there were numerous fibers in the lungs of these people, but their previous occupations were not well documented. I appreciate your comment. I think that it is something that perhaps needs to be pursued.

QUESTION (Chairman Rowe): Did you examine any other tissues to see if there were particles in those tissues? And this is a general question: What is the relationship between a granulomatous response and, say, the development of fibrosis, if any?

ANSWER (Dr. Reinhardt): We did not examine the other tissues specifically to see if there were fibers that had been translocated. I would like to refer that second question back to Dr. Lee, our pathologist.

ANSWER (Dr. Lee): We checked lymph nodes and after 1 week the small particulates were transferred to lymph nodes without any significant inflammatory reaction. Your second question regarding pulmonary fibrosis; it was not striking to observe the more fibrogenic reaction in the large granuloma. So we think these are nonfibrogenic fibers.

ENVIRONMENTAL EXPOSURE CONSIDERATIONS DUE TO THE RELEASE OF GRAPHITE FIBERS DURING AIRCRAFT FIRES

by

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ABSTRACT

Estimates are developed of the environmental criteria associated with micron size carbon fibers released from burning graphite composites during aircraft fires. Empirical fiber distributions were determined from test results of exposure of graphite composite structural elements to large pool fires. Frequency and dimensions of the micron carbon fibers were characterized. Fibrillated particles were observed which constituted the predominant source of the micron fiber data. The fibrillation phenomena were attributed to fiber oxidation effects caused by the fire environment. Estimates were established of micron carbon fiber concentration and exposure levels for an extreme case of an aircraft accident, and comparisons were made with OSHA criteria for asbestos exposure.

Estimates have been developed of the dimensions and frequency of occurrence of small-diameter carbon fibers released from burning graphite composites during aircraft fires as a frame of reference for comparison with environmental exposure criteria established for known fiber hazards.

Development of the micron fiber criteria was based principally on data reduction and analysis of sticky paper records obtained during large pool fire tests of spoiler and cockpit structural samples conducted at the Naval Weapons Center, China Lake, in May 1978.[1] The sticky paper instrumentation consisted of sheets of adhesive coated paper of approximately 20 cm x 25 cm in dimensions located on wooden platforms of about 0.6 m height above ground. Station locations ranged about 75 m to 115 m from the test samples covering an arc of about 100 degrees. Data reduction consisted of determining carbon fiber dimensions by means of optical microscopy.

An effort was made to determine appropriate diameter and length bounds for carbon fibers that may be potentially respirable by humans and of interest toward establishing fiber hazard criteria. There appears to be evidence that durable fibers of similar dimensional characteristics constitute health hazards simply because of physical properties rather than chemical nature.

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Extensive studies have been performed regarding health hazards associated with asbestos and glass fibers with very limited research relative to carbon fibers.

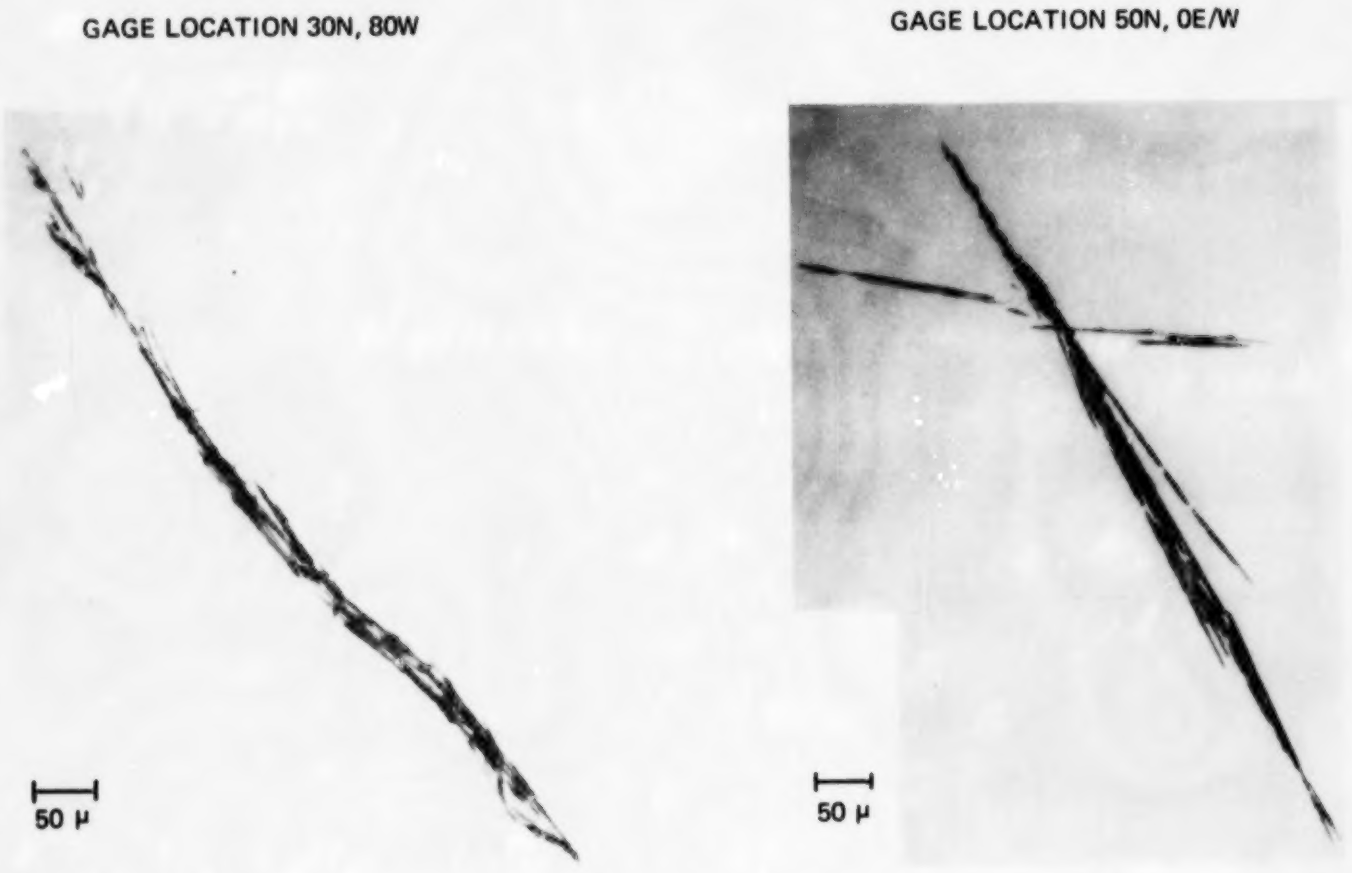
Due to the lack of specifically developed guidelines regarding carbon fiber hazards it has been generally recommended that the existing framework of information on asbestos and glass fibers may be applied toward establishing bounds on carbon fiber criteria. Based on a review of the state of the art[3-7] the limiting carbon fibers dimensions of interest toward health hazards were assumed as follows: (1) diameter less than 3 microns, (2) length less than 80 microns, and (3) length-to-diameter ratio of 3 or greater.

During the course of data reduction of the NWC sticky paper records particles were observed which manifested a splitting or fibrillation process in that single fibers appeared to be segmented longitudinally along the axis of the fiber into individual fiber elements or essentially fibrils. Examples of particles of this nature are shown in Figure 1. In some cases the particles are characterized by substantial fragmentation of the slender fibers into short segments. Representative fibrillated fibers with high micron particle density are shown in Figure 2, with an enlarged view of a high density region presented in Figure 3.

Evaluation of the NWC data indicated that the fibrillated particles constituted the predominant source of micron size fibers of interest toward consideration of potential health hazards. An effort was made to separate some of the fibrillated particles from the adhesive on the records for detailed examination by means of a scanning electron microscope. However, a difficulty developed in preparation of the fiber sample for SEM photography in that complete removal of the adhesive was not possible without a thin layer adhering to the fiber surface. This layer was significantly greater than the depth of focus of the SEM equipment, and therefore, the particle could not be observed.

Recommendation was made to NASA that Petri dish instrumentation be incorporated in forthcoming pool fire tests of graphite composite structures at the Dugway Proving Ground in order that free carbon fibers may be collected unencumbered by the adhesive coating associated with sticky paper records. The DPG tests were conducted during October-November 1979. Petri dish instrumentation was distributed over an arc of about 120 degrees at a distance of approximately 110 m from the test samples. A comparison of the NWC and DPG test characteristics is presented in Table 1.

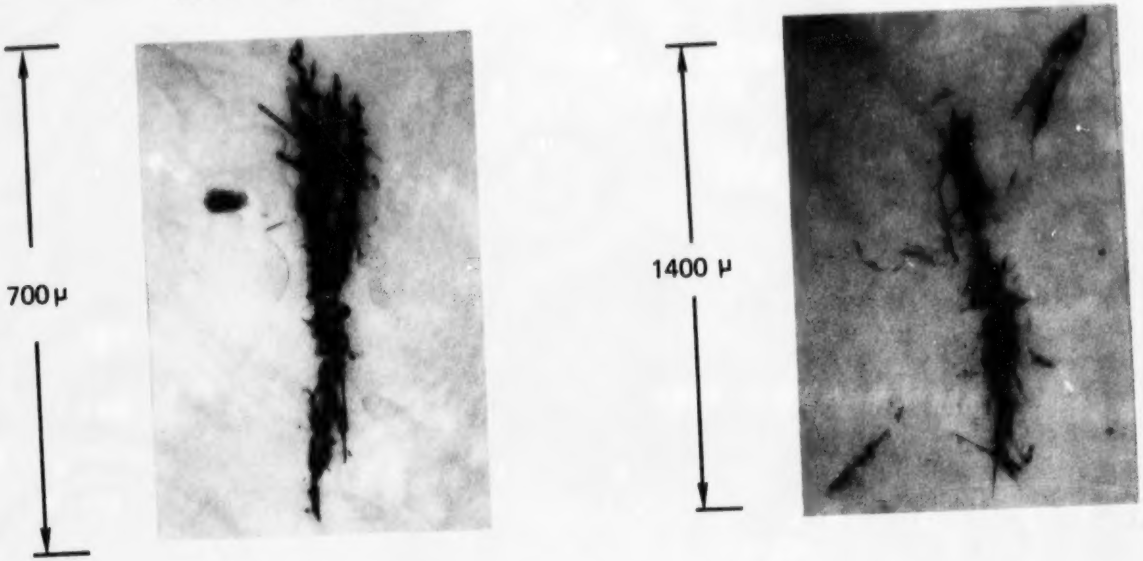
Analytical results for the length versus diameter distribution for NWC 11 is shown in Table 2, with a similar tabulation for NWC 13 given in Table 3. For the case of NWC 11 a total of 191 micron fibers ($D<3\mu$, $L<80\mu$) were observed with a corresponding frequency of occurrence of 38.4 percent. The number of single fibers with lengths $\geq$ 1 mm was 32, or 6.4 percent. The ratio of micron fibers to single fibers with $L \geq 1$ mm was therefore 6.0. Relative to the NWC 13 data, 262 micron fibers were measured with a frequency of 49.5 percent. The number of single fibers with $L \geq 1$ mm was 30, or 5.7 percent. The ratio of micron fibers to single fibers with $L \geq 1$ mm was 8.7.



GAGE LOCATION 30N, 80W

GAGE LOCATION 50N, 0E/W

Figure 1. Examples of Fibrillation Effect During NWC Spoiler Test 11.



NWC 11 - 140N, 60W

NWC 13 - 180N, 40W

Figure 2. Representative Fibrillated Fibers with High Micron Particle Density

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NWC 13 - 180N, 40W

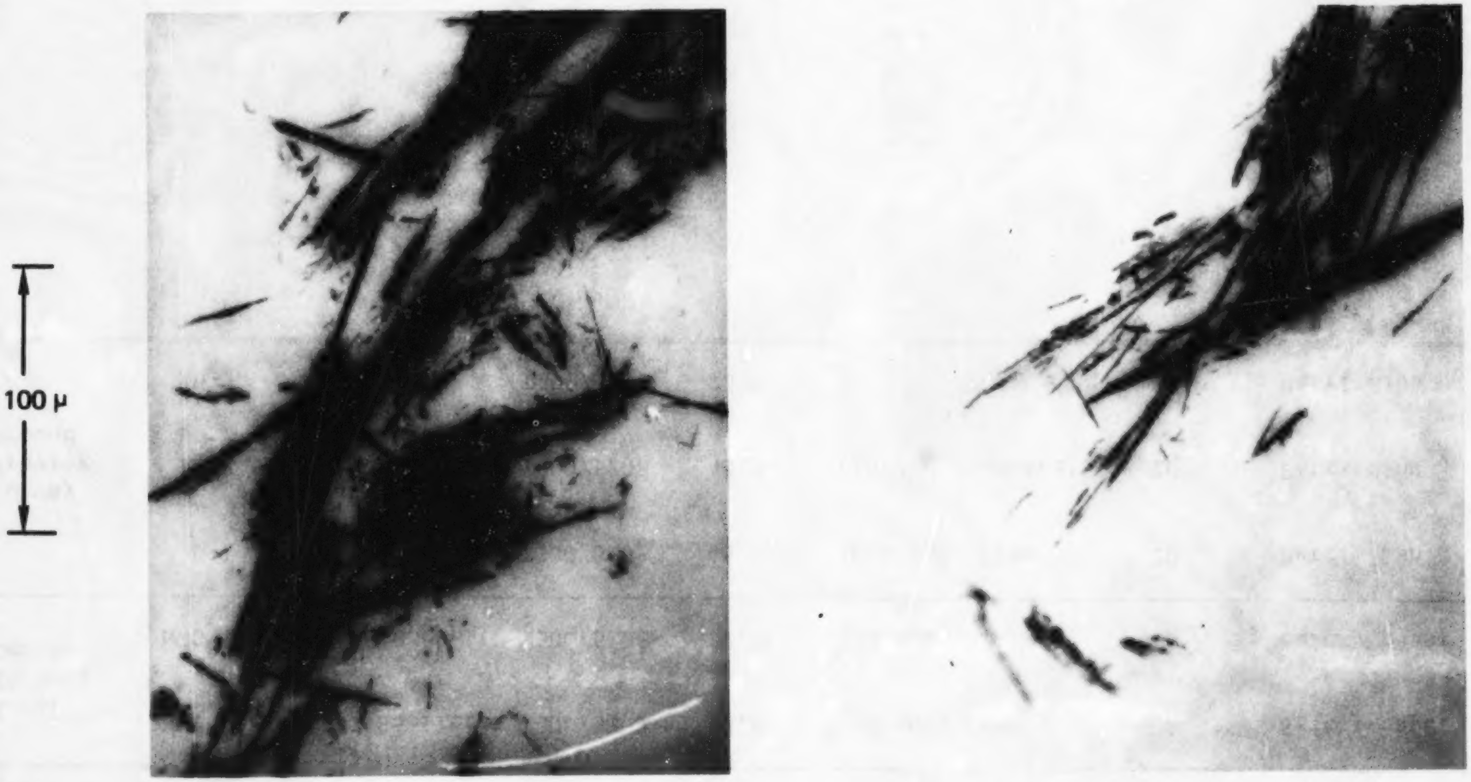

Figure 3. Enlarged View of High Micron Particle Density Region

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TABLE 1. TEST DATA SOURCES

Test location	Test designation	Test sample	Composite type	Composite mass (kg)	Test configuration	Burn duration (min)	Test instrumentation
Naval Weapons Center	NWC 11	737 Spoilers	T300/5209	3.8	JP-5 pool fire	4	Sticky paper
	NWC 13	F-16 Cockpit	T300/5208	22.5	(12 m x 18 m)	6	Sticky paper
Dugway Proving Ground	D-1	Various structural elements	T300/5208	46.2	JP-4 pool fire	20	Petri dish
	D-2		T300/5208	45.5	(10.7 m diameter)	20	Petri dish
	D-3		T300/5208	70.8		20	Petri dish

TABLE 2. SPOILER TEST NWC 11--LENGTH VS DIAMETER CORRELATION

Diameter interval (microns)	Length interval (microns)												Total	Percent
	5-10	10-20	20-40	40-75	75-150	150-300	300-600	600-1000	1000-2000	2000-4000	4000-8000	8000-16,000		
0-1	12	17	8	2	4	-	-	-	-	-	-	-	43	8.7
1-2	6	18	33	17	8	3	1	1	-	-	-	-	87	17.5
2-3	-	21	22	28	23	14	7	3	2	1	1	1	122	24.5
3-4	2	5	5	4	11	10	10	2	5	2	1	-	57	11.5
4-5	2	5	3	-	9	7	6	5	3	4	1	-	45	9.1
5-6	-	1	1	2	6	5	5	2	4	-	-	-	26	5.2
6-7	-	2	3	6	6	4	9	5	4	-	-	-	39	7.8
7-8	-	1	1	4	3	-	4	2	2	1	-	-	18	3.6
>8	-	1	15	23	5	1	4	7	2	1	1	-	60	12.1
Total	22	71	91	86	75	43	46	27	22	9	4	1	497	100.0
Percent	4.4	14.3	18.3	17.3	15.1	3.7	9.3	5.4	4.4	1.8	0.8	0.2	100	

TABLE 3. COCKPIT TEST NWC 13--LENGTH VS DIAMETER CORRELATION

Diameter interval (microns)	Length interval (microns)													
	5-10	10-20	20-40	40-75	75-150	150-300	300-600	600-1000	1000-2000	2000-4000	4000-8000	8000-16,000	Total	Percent
0-1	14	16	18	6	1	-	-	-	-	1	-	-	56	10.6
1-2	11	30	57	36	30	11	2	2	-	-	-	-	179	33.8
2-3	-	7	31	27	32	14	7	4	10	3	-	-	135	25.5
3-4	-	1	5	9	5	14	7	5	7	-	2	1	56	10.6
4-5	-	-	1	3	4	7	6	1	3	-	-	1	26	4.9
5-6	-	-	-	-	7	2	2	1	1	-	-	-	13	2.5
6-7	-	-	-	-	5	3	2	2	1	-	-	-	13	2.5
7-8	-	-	-	2	4	4	3	1	-	-	-	-	14	2.6
>8	-	-	-	1	5	8	5	6	8	4	-	-	37	7.0
Total	25	54	112	84	93	63	34	22	30	8	2	2	529	100.0
Percent	4.7	10.2	21.2	15.9	17.6	11.9	6.4	4.1	5.7	1.5	0.4	0.4	100	

The ratio of fibrillated fibers to nonfibrillated fibers was 22 percent in the case of NWC 11 as compared to 30 percent for NWC 13. An average number of about 10 individual particles per fibrillated fiber were observed for both sets of data. In general, the distributions for the two tests were quite similar. Therefore, it appeared reasonable to assume a combination of the associated micron fiber data for the purpose of the present criteria analysis. A comparative plot of the integrated micron fiber characteristics encompassing a total of 1026 fibers is shown in Figure 4. Although not indicated, the lower limits for the plots of Figure 4 were respectively 0.4 microns for diameter, 2 microns for length and 3 for length to diameter ratio.

With reference to Tables 2 and 3, the average frequency of occurrence for NWC 11 and NWC 13 of single fibers in the micron fiber domain is 44 percent as compared to 6 percent for lengths greater than or equal to 1 mm, or a ratio of 7.3. To account for incomplete data reduction of the fibrillated fibers, it appears reasonable to increase this ratio to 10.

It is noted that a predominant portion of the observed particles in the micron domain of diameters less than 3 microns and lengths less than 80 microns were associated with fibrillated fibers. In the data reduction of the NWC sticky paper records location of isolated particles of such dimensions was extremely difficult since the frequency of occurrence was quite small. It is quite probable that particles of this size with very low settling velocities would have been dispersed to significant distances downrange before being deposited on the ground.

A study by means of SEM photography of free carbon fibers collected during the DPG tests yielded an insight into the causes of fibrillation effects. Examples of the different manifestations of the fibrillation phenomena are shown in Figures 5 and 6 with arbitrary categorization of the types of effects. These photographs offer striking evidence of the spectrum of oxidation effects caused by the fire environment leading to what has been designated as fibrillation phenomena and indicating conclusively a source of micron size fibers from a parent single carbon fiber.

It was of interest to study the pattern of separation of single fibrils of significant lengths. The result in one case is reflected by the sequence of photographs presented in Figure 7, each corresponding to 3000X magnification with the indicated vertical scale of 2 microns and horizontal scale of 50 microns applicable similarly to each photograph. The overall length covered was about 250 microns. Each photograph is essentially an extension at the left of the photograph immediately adjacent and directly below it with a small overlap for continuity and identification.

Separation of the two fibrils in the uppermost photograph appear to continue over a length of about 100 microns until the advent of a third fibril in the middle photograph. Subsequently the three fibrils merge within a length of about 125 microns with evidence only of a single fine line of separation at the termination in the bottom photograph. At the far right of the bottom photograph, a fiber is noted with an average diameter of about 1 micron and length of about 20 microns. However, over a length of about 3 microns at each end the fiber diameter is gradually reduced down to a value of a small

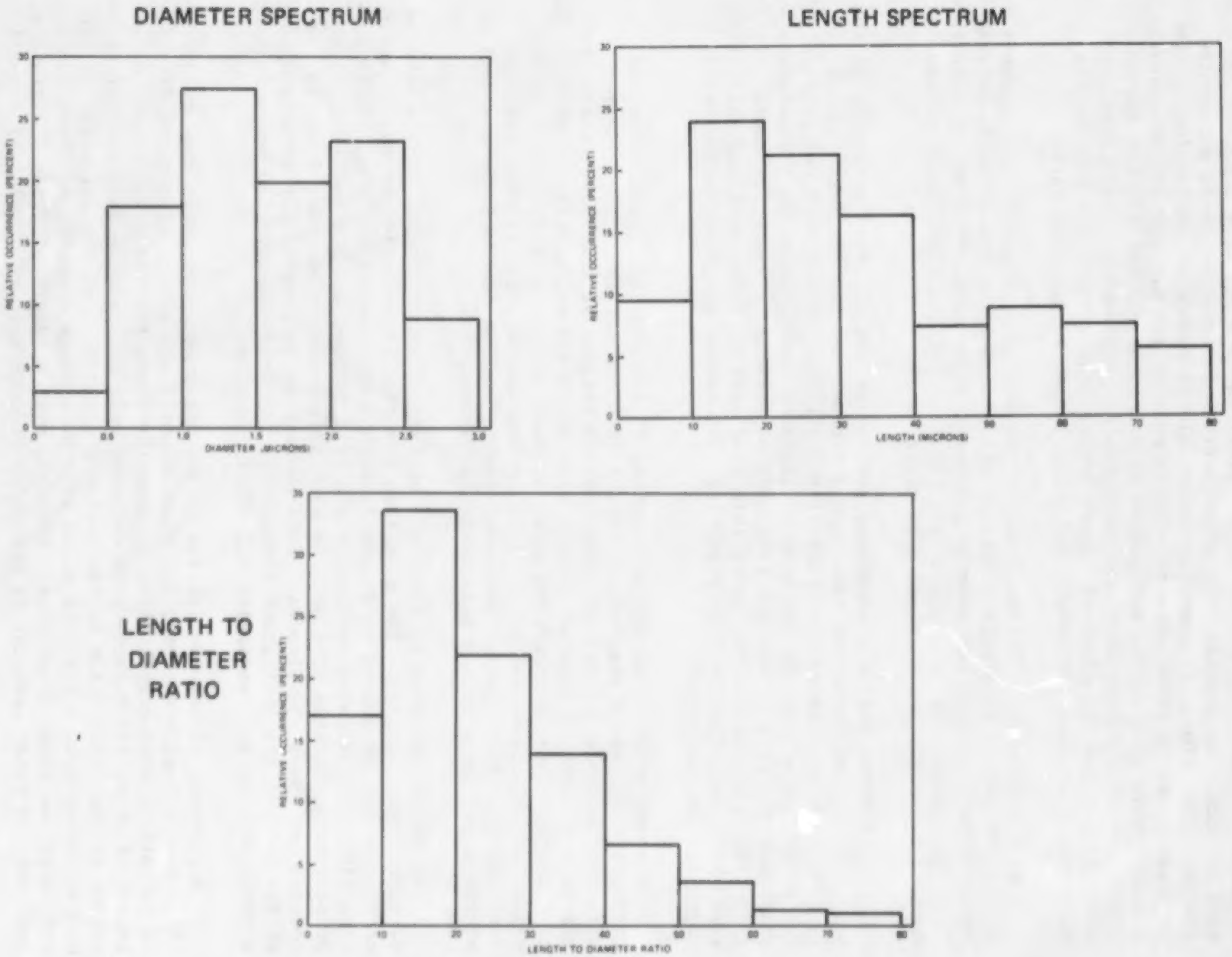


Figure 4. Micron Fiber Characteristics

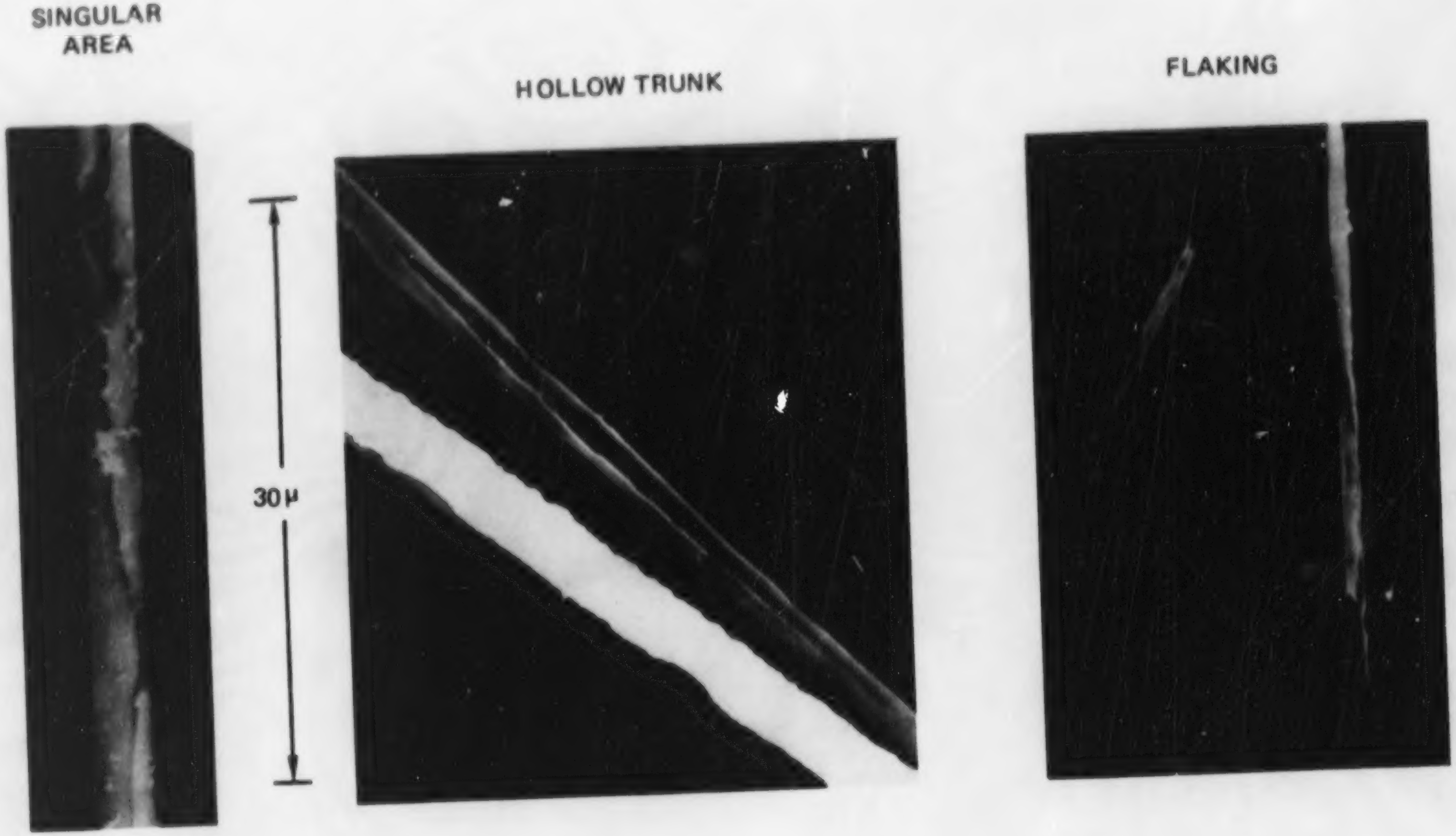
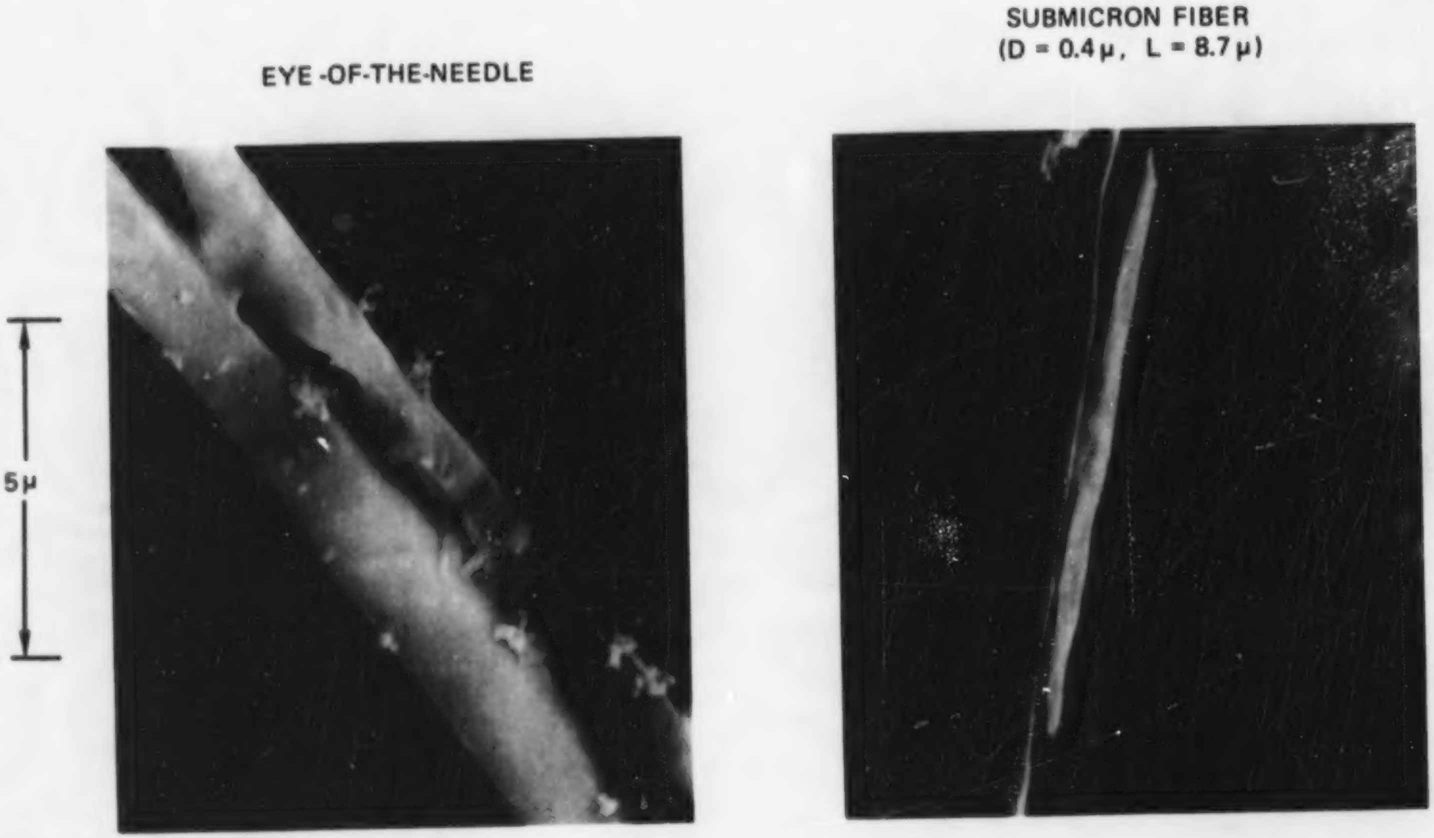

SINGULAR AREA
HOLLOW TRUNK
FLAKING
30μ

Figure 5. Representative Fibrillation Effects - I



EYE-OF-THE-NEEDLE

SUBMICRON FIBER
(D = 0.4μ, L = 8.7μ)

Figure 6. Representative Fibrillation Effects - II

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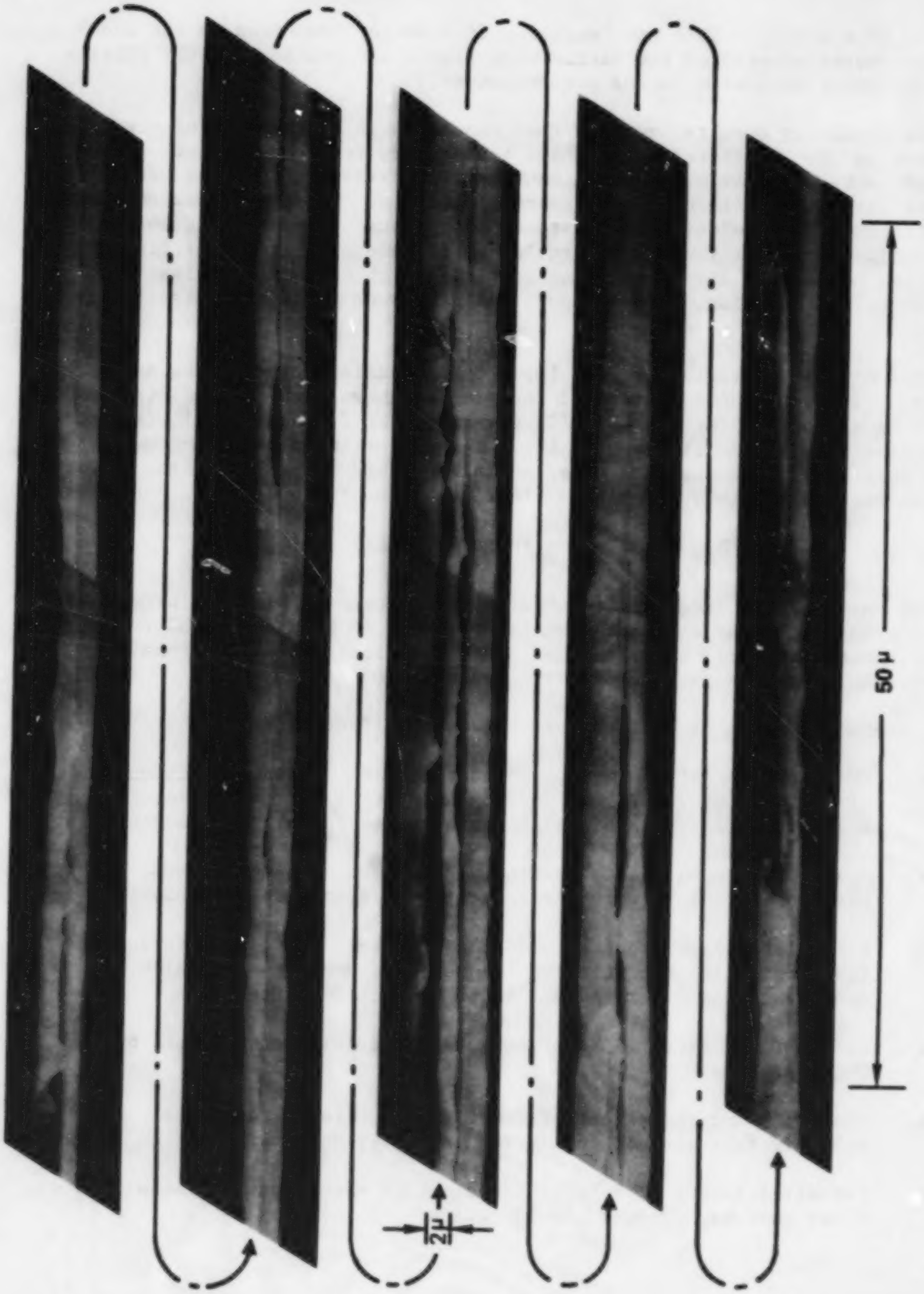

Figure 7. Fibrillation Phenomena Over Extended Length

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fraction of a micron. This manifestation of diameter reduction at the ends is quite characteristic of the micron size fibers associated with the fibrillated particles evaluated in the present study.

The foregoing results indicate that considerable degradation of the fiber structure may be attributed to the high temperature fire environment. There appeared to be singular areas where preferential oxidation occurred with frequent irregular patterns in the fibril evolution. Studies of carbon fiber microstructure[8-12] indicate the existence of various types of precursor defects (inorganic particulate, irregular voids) and graphite fiber flaws (cavities, pockets of low crystalline density) which can affect oxidation resistance. In addition, sodium impurities can cause catalytic oxidation in carbon.

Micron fiber criteria were developed on the basis of the following methodology: (1) assume NASA criteria[13] for single fibers with lengths greater than or equal to 1 mm ($N_L \geq 1$ mm), (2) determine the frequency ratio (FR) of micron fibers to single fibers with $L \geq 1$ mm, (3) estimate an enhancement factor (EF) to account for data base limitations, and (4) multiply the respective factors to yield the micron fiber number as follows:

$$N_{MF} = (N_{L \geq 1\ mm}) \times (FR) \times (EF)$$

As noted earlier, the frequency ratio of micron fibers to single fibers of lengths greater than or equal to 1 mm is estimated to be a factor of 10. However, there are various limitations and uncertainties regarding the data base available for the purpose of establishing this ratio.

A number of these limitations are briefly outlined as follows:

- Considerable difficulty was encountered in the data reduction of isolated micron fibers due to the sparcity of occurrence to the extent that data of this nature was essentially discounted.
- Analytical results encompass only data from close-in ranges with no basis for judgement regarding downrange characteristics.
- Fibrillated fibers constituted the principal source of micron fiber data with the relative frequence of occurrence of high density micron fiber regions as somewhat indefinite.
- Micron fiber criteria have been evaluated only on the basis of NWC test data.
- Prediction of the extent of fibrillation effects associated with aircraft accident scenarios is highly uncertain.
- Potential impact of significant diameter reductions at the micron fiber ends may warrant consideration.

- Data collection technique involving pressure of protective acetate cover sheet over sticky paper adhesive surface may have contributed toward separation of micron fibers from parent fibrillated particles.

- Appropriate scaling factors for increased composite mass and complex structural configurations are unavailable.

- Micron fiber source enhancement due to wind conditions, explosions, turbulence and mechanical disturbances has not been evaluated.

On the basis of the foregoing limitations, it appears reasonable to introduce an enhancement factor of 10 in the frequency ratio of micron fibers to single fibers with lengths greater than or equal to 1 mm.

Micron fiber criteria estimates based on the analyses of the present study are presented in Figure 8. The total number of micron fibers per kilogram mass of carbon fiber released is specified as 5×10^{11}, with a corresponding micron fiber mass fraction of carbon fiber released as 5 percent. The spectral distribution of micron fiber dimensions reflects a relatively uniform pattern over the respective diameter and length intervals.

The criteria values of Figure 8 constitute a description of the micron fibers generated at the source during an aircraft accident involving a fire only. It appeared of interest to evaluate an extreme case estimate of the potential exposure to the micron fiber plume propagating downwind. Results of the upper limit estimates are shown in Figure 9.

The mass of carbon fiber exposed to the fire was assumed as 1000 kg resulting in a total number of 5×10^{12} micron fibers released. A schematic of the carbon fiber plume profile is shown in Figure 9. For the purpose of the present analysis no consideration is given to the particulate rainout occurring in the close-in regions, with attention focussed principally on exposures beyond the plume cross-section designated in Figure 9 as downrange source area. No loss of micron fibers is considered for the close-in areas with the total source of 5×10^{12} micron fibers assumed available for propagation downrange. In addition, reduction of concentration levels due to dispersion of the fiber cloud is neglected.

The peak carbon fiber concentration and exposure levels were estimated as:

$$(C_{CF})_{max} = 5.3 \times 10^6 \text{ f/m}^3$$

$$(E_{CF})_{max} = 3.2 \times 10^8 \text{ f-s/m}^3$$

Corresponding values for the OSHA asbestos standard[3] are:

$$C_{AS} = 2 \times 10^6 \text{ f/m}^3 \text{ (8-hr time weighted average)}$$

- MICRON FIBER FREQUENCY RATIO RELATIVE TO SINGLE FIBER LENGTHS $\geq$ 1MM 10
- ENHANCEMENT FACTOR TO ACCOUNT FOR LIMITATIONS AND UNCERTAINTIES 10
- MICRON FIBERS PER KILOGRAM MASS OF CARBON FIBER RELEASED
  - ASSUME NASA VALUE FOR LENGTHS $\geq$ 1MM = 5×10^9 FIBERS
  - MULTIPLY BY MICRON FIBER FREQUENCY RATIO AND ENHANCEMENT FACTOR

    NUMBER OF MICRON FIBERS $= \left(5 \times 10^9\right) \times \left(10\right) \times \left(10\right) = 5 \times 10^{11}$
- MICRON FIBER DIMENSIONS

LENGTH (MICRONS)	PERCENT OF TOTAL	DIAMETER (MICRONS)	PERCENT OF TOTAL
2 – 10	10	0.4 – 1.0	21
10 – 20	24	1.0 – 1.5	27
20 – 30	21	1.5 – 2.0	20
30 – 40	16	2.0 – 2.5	23
40 – 60	16	2.5 – 3.0	9
60 – 80	13	–	–

- MICRON FIBER MASS PER KILOGRAM OF CARBON FIBER RELEASED
  - AVERAGE MASS PER FIBER: $\overline{M} = \frac{\pi}{4} \overline{D}^2 \overline{L} \rho = \frac{\pi}{4} \left(1.5 \times 10^{-4}\right)^2 \left(30 \times 10^{-4}\right) \left(1.8\right) = 1 \times 10^{-10}$ GM
  - TOTAL MICRON FIBER MASS: $M_T = \left(5 \times 10^{11}\right) \left(1 \times 10^{-10}\right) = 50$ GM
  - MASS FRACTION OF CF RELEASED: 5 PERCENT

Figure 8. Micron Fiber Criteria Estimates

- MASS OF CF EXPOSED TO FIRE 1000 KG
- MASS OF CF RELEASED (1%) 10 KG
- NUMBER OF MICRON FIBERS RELEASED 5×10^{11} PER KG
- TOTAL MICRON FIBERS RELEASED 5×10^{12}
- CONCENTRATION $C = \dfrac{N_f}{\frac{\pi}{4} D_s^2 V_w t_b}$

  N_f = FIBER NUMBER

  $\frac{\pi}{4} D_s^2$ = SOURCE AREA

  V_w = WIND VELOCITY

  t_b = BURN TIME

- PARAMETER ASSUMPTIONS

  $D_s = 200\text{M}$ $V_w = 0.5$ M/SEC $t_b = 60$ SEC

  $$\text{CONCENTRATION} = \frac{5 \times 10^{12}}{\frac{\pi}{4}(200)^2\,(0.5)(60)} = 5.3 \times 10^6 \text{ F/M}^3$$

  EXPOSURE = CONCENTRATION X BURN TIME

  $$= (5.3 \times 10^6)(60) = 3.2 \times 10^8 \ \frac{\text{F} - \text{S}}{\text{M}^3}$$

- OSHA ASBESTOS STANDARD : CONCENTRATION $2 \times 10^6 \ \frac{\text{F}}{\text{M}^3}$

  EXPOSURE $5.8 \times 10^{10} \ \frac{\text{F-S}}{\text{M}^3}$ PER 8 - HR DAY (CUMULATIVE)

CARBON FIBER PLUME PROFILE

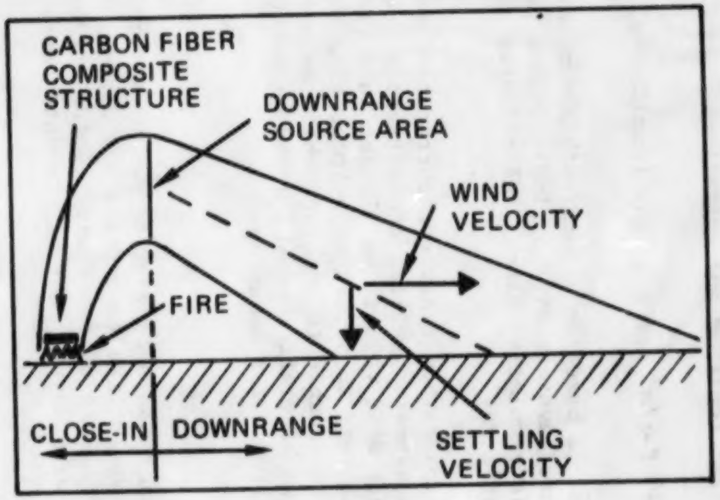
CARBON FIBER
COMPOSITE
STRUCTURE
DOWNRANGE
SOURCE AREA
WIND
VELOCITY
FIRE
CLOSE-IN
DOWNRANGE
SETTLING
VELOCITY

Figure 9. Upper Limit Estimate of Micron Fiber Exposure

$$(C_{AS})_{max} = 1 \times 10^7 \text{ f/m}^3 \text{ (ceiling concentration)}$$

$$E_{AS} = 5.8 \times 10^{10} \text{ f-s/m}^3 \text{ per 8-hr day (cumulative)}$$

The OSHA asbestos exposure level is based on a permissible concentration level of 2×10^6 f/m^3 as a time-weighted average over a single 8-hour period (2.9×10^4 sec). The exposure level is cumulative since OSHA criteria permit similar exposures for each successive work day.

The upper limit of the micron carbon fiber concentration level is only about half the permissible OSHA asbestos ceiling concentration level. Consideration of factors such as higher wind velocities, longer burn times and downrange plume dispersion would lead to values even lower than the OSHA asbestos standard. It appears reasonable to conclude that the micron fiber exposure levels resulting from an aircraft accident would be substantially lower than the OSHA standard criteria for asbestos.

ACKNOWLEDGMENTS

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DISCUSSION ON GRAPHITE FIBERS

REMARK (Dr. Corn): I am associated with the John Hopkins University. My comments are relative to the last presentation which I found an interesting diversion in science fiction until you invoked the OSHA standards for asbestos. You must be aware, Dr. Sussholz, that the OSHA standard is one of using a surrogate for the total number of asbestos fibers present. It is implicit that the standard sample should be used and analyzed in a standard manner. You sampled in a nonstandard grossly inefficient manner for precisely the inhalable particles associated with asbestos risk. You cannot expect to capture those by a sedimentation method or a sticky paper method. You then superimposed upon that extrapolation of values what I would call "finagle factors" and an interesting construct, all of which I am perfectly willing to listen to. But do not then compare that to a meaningful standard for the assessment of risk to inhalation of fibers. I would submit here that the analysis is just totally incorrect.

REMARK (Dr. Sussholz): I guess my concluding remarks, which attempted to reflect the uncertainties and the application of the results with reference to the general areas of interest here, were insufficient to allay the fears of this gentlemen. I cannot disagree with any of the comments you made; you are free to your own opinion. This was the best we could do under the circumstances. It turned out to be the first study of its nature. And in any manner that additional work can be supported in any way anywhere at all, that is a wonderful idea.

QUESTION (Mr. Wagner): I am from Dupont. Dr. Sussholz, do you have any data on the number of micron size particles generated in machining or cutting of a carbon fiber reinforced composite?

ANSWER: (Dr. Sussholz): Not that I am aware of. We do not have data of any nature along those lines, and I am not aware of a study that has been performed where this type of information was of prime interest.

CROSS-SECTIONAL MEDICAL STUDY OF WOLLASTONITE WORKERS

by

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ABSTRACT

Wollastonite is a fibrous monocalcium silicate with widespread use in ceramics and as a substitute for asbestos. Workers at the only U.S. wollastonite mine and mill were studied with spirometry using air and 80% helium-20% O_2, chest x-ray, physical examination, and respiratory questionnaire. Diffusing capacity of the lung (D_{LCO}) was measured in 23 workers with over 15 years' exposure. Overall, 104 men (72% of all those with at least 1 year of exposure) were studied. Air samples were collected at the work site on Millipore filters and fiber counts performed with phase contrast microscopy. An exposure index was calculated by multiplying mean count of fibers (greater than 5 micrometers in length) per cc x years of work.

Symptoms of chronic bronchitis were present in 23% of smokers and ex-smokers and in 9% of non-smokers. However, there was no association of prevalence of bronchitis with increasing exposure index. A reduction in forced vital capacity (FVC) below the predicted range was found in only 1 worker. Although 20% of smokers and ex-smokers had a forced expired volume in 1 second (FEV_1) less than 70% of FVC, no significant correlation of obstructive impairment or forced expiratory flow at 50% of vital capacity with exposure index was found for air or helium-O_2 spirometry. One subject who has polycythemia vera had an abnormal D_{LCO}. Four men without other abnormalities had chest x-rays showing Category 1, type q, rounded opacities. No irregular opacities or pleural plaques were noted. Five workers, all current or past smokers, had crepitations in the lungs, not associated with x-ray changes. Wollastonite is similar to asbestos, but we were unable to demonstrate the usual stigmata of asbestos exposure. Because only 36% of men studied had over 15 years' exposure, further followup is needed to determine if wollastonite is truly less hazardous than asbestos.

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*Presented by Dr. Brian Boehlecke. This study may be found in Dust and Disease, "Respiratory Morbidity of Workers Exposed to Wollastonite through Mining and Milling." John Dement and Richard Lemmens (Eds.), Pathotox Publishers, 2405 Bond Street, Park Forest South, IL 60466, (1979) p. 251-256.

DISCUSSION ON WOLLASTONITE

REMARK (Mr. Clifton): I am from the U.S. Bureau of Mines.

I see you are looking for substitutes for asbestos all over the place and it is very nice to find one that has many of the same properties as asbestos with no apparent health effects. A word of caution, though. Some of these substitute materials are very finite resources and reserves, which means that if they were purported to replace asbestos in large areas, the cost could go up astronomically. Wollastonite happens to be one with very small reserves and resources.

QUESTION (Dr. Gross): I am from the Industrial Health Foundation.

While you were talking I looked at a graph of the relationship of alveolar deposition, that is deposition in the air spaces against the diameter and length of the fiber. As I understand it, the average wollastonite fiber was in excess of 2 micrometers in diameter, is that correct?

ANSWER (Dr. Boehlecke): No. Two and a half micrometers in length, and 0.22 micrometers in diameter.

REMARK (Dr. Gross): In that case, I do not have any information on that. But if it had been 2 micrometers in diameter, it would have had a deposition in the air space of only 2 percent.

REMARK (Dr. Boehlecke): No, it is 0.22.

ENDEMIC PLEURAL DISEASE IN RELATION TO ZEOLITE EXPOSURE

by

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ABSTRACT

Pleural mesothelioma, lung cancer, pleural and parenchymal fibrosis appear to be endemic in an agricultural area of Cappadocia, Turkey. Initial observations indicate that asbestos does not occur nor is it used. However, fibrous zeolite minerals appear to be widely distributed there. The verification of this supposition may provide information on a troubling and unresolved public health question. With the recognition of significant hazards associated with exposure to asbestos, caution has been suggested on the basis that substitute commercial fibers may have similar biological activity. This concern is reinforced by Stanton's hypothesis that the toxicity of inorganic fibers depends more on their shape and size than on physical-chemical factors. Human experience bearing on the question for evaluation has been heretofor lacking. The affected area was visited and a large number and variety of environmental samples, as well as lung tissue of individuals with mesothelioma and other thoracic disease were collected. These samples are being analyzed to establish the mineral assemblages present to permit correlation of observed disease with microparticulate exposures which may have occurred.

More than 50 cases of pleural mesothelioma have been reported during the period from 1974-78 in a relatively small area of Turkey, centered in and around the villages of Karain and Tuzköy, in the province of Cappadocia. The incidence of malignant pleural mesothelioma in this area for exceeds any rate for any population not known to be asbestos-exposed. Moreover, calcified plaques, pleural thickening and parenchymal scarring are also prevalent in these populations. Plaques and scarring are often stigmata of exposure to asbestos, leading to mesothelioma. No outcroppings of asbestos-containing rocks, nor asbestos mines or industries, are known to exist in this area. However, another group of silicate minerals is present. This group of minerals is called zeolites and it includes fibrous types, having fiber dimensions similar to some asbestos fibers. The area of Karain and Tuzkoy is covered with volcanic tuffs, which are altered in places to form a range of zeolite minerals. The volcanic tuff consists principally of glass fragments (including glass fibers), quartz, plagioclase feldspar and pyroxene minerals. In addition to zeolites, other alteration products such as montmorillonite, cristobalite and tridymite are found. The tuffs in this area of Turkey are generally soft and friable and are subject to wind erosion. The tuff building stones are hand-cut from local quarries located in hills and cliffs adjacent to the different villages for construction purposes. A large proportion of the houses in Karain are actually caves, excavated by hand from the soft tuffaceous rock. The village of Karain itself abuts the steep valley wall which overlooks the town. In addition to houses, a number of holes and caves have been excavated in the nearby outcropping of tuff for use as animal pens, food storage areas, and fodder storage areas. Pigeon excrement, the only fertilizer used, is collected by villagers from the nest-holes in the tuff. In the homes, and in the excavated caves, and in agricultural pursuits, constant contact is made with settled dusts, soils and rock surfaces. The floors of the homes tend to be the soil surface. Also, in many homes, the use of pulverized white soil, locally collected for whitewash is also common. The roads in the area are for the most part unpaved. Winds, vehicular traffic, and other activities in this semiarid climate results in the generation of large amounts of airborne dust. Agriculture and animal husbandry are virtually the only occupations. The effect of these circumstances is to expose the populations of the villages to high levels of airborne dust, originating from the host rock, throughout their entire lives. While some villages have the appearance of being dustier than others, the observed differences in levels of pleural diseases among the villages in the area may be the result of either differences in the kinds and amounts of dust exposures, or both. The mineralogical characterization, both quantitative and qualitative, of these materials affords an important foundation for the evaluation of the biological problems.

With the cooperation of the Turkish scientists studying the Cappadocia situation, we visited the area and obtained a large number and variety of rock and environmental samples such as house and road dust, local whitewash, pertinent geological samples, building stone as well as lung tissue of individuals with mesothelioma and other thoracic disease. These samples are being analyzed to establish the exact mineral assemblages present and to permit correlation of observed disease with dust exposures which may have occurred.

The incidence of mesothelioma is of particular interest since this cancer has been considered to be a "marker disease" for asbestos exposure. Recent studies suggest that most mesotheliomas (80-95 percent) can be traced to asbestos exposure. (1) In the village of Karain, in Cappadocia, with a total population of 604, there were 11 deaths due to pleural mesothelioma of a total of 18 in 1974. In the previous five years, 25 pleural mesotheliomas were reported from the same village. (2) On the basis of a study carried out in a nearby village, Tuzköy, with a population of about 3,000, it was found that the incidence of pleural mesothelioma is at least 6.5 patients per year, or about one thousand times more than expected. (3) It is of interest to note that these data were accumulated by the Chest Service of a large Turkish medical center, so that peritoneal mesothelioma may remain largely unreported, although it is known to have occurred. It is possible that even this extraordinary finding may be significantly underestimating the true incidence of mesothelioma because of the remoteness of the area and the general lack of medical services in the region.

The results of this study may be expected to provide information regarding the validity of the Stanton hypothesis. (4,5,6) Stanton suggested, based on experimental observations, that the exposure of animals to fibrous materials produces greater cancer risk than the exposure to identical materials which are non-fibrous. For example, the intrapleural injection of fibrous materials of diverse types and size distributions into animals produces malignant tumors significantly related to fiber shape and a narrow size range of fibers. It is stated that the "simplist incriminating feature for both carcinogenesis and fibrogenesis seems to be a durable fibrous shape, perhaps in a narrow size range. (6) Stanton observed that long, thin fibers produced proportionally more mesotheliomas when implanted in the rat. In addition, the experiments of Pott and Friedrichs, (7), and Pott, Huth and Friedrichs (8) indicated that the carcinogenic (mesothelioma) potency of a mineral depended upon shape factors, the fibrous forms tending to be more carcinogenic. Therefore it appears reasonable that the focus for search of a physical etiologic agent in association with mesothelioma should fall on mineral fiber. For one fiber, asbestos, documentation concerning the relation to mesothelioma is extensive. In Turkey, since endemic mesothelioma and other pleural diseases occur without apparent asbestos exposure, other mineral fibers, possibly fibrous zeolites, may be implicated. An important objective will be to confirm the alleged absence of asbestos in environmental samples. Since there are no asbestos mines or mills and since there is no use of commercial asbestos products by the villagers, it has been argued that asbestos is not the etiologic agent. This argument is based on the speculation that the geological nature and history of the area are highly unfavorable for the occurrence of asbestos deposits, commercial or otherwise. However, Cappadocia covers an area of over 1,500 square kilometers, mostly remote and inaccessible. The geology is highly complex and has not been studied in sufficient detail to fully exclude the possibility that asbestos minerals may occur in the area. They may or may not occur in or near the villages. They may be exogeneous, brought from distant sources. For example, it is common practice in the region for the villagers to stucco or whitewash their dwellings for hygienic and esthetic purposes. Preparation, application and removal of the whitewash produces visable dust, and surface erosion of the whitewash may add to this dust. Each village obtains its own supply of whitewash from various, unknown sources. Asbestos minerals may occur with some types of light-colored rocks, such as metamorphosed limestones.

ZEOLITES

Zeolites are hydrated aluminum silicates, with alkaline metal and alkaline earths substituting within the framework structure. The water of hydration is both variable and reversible, and cations may readily substitute within the structure. The corners of the silica tetrahedron are shared, producing a three-dimensional lattice, and substitution of aluminum for silicon in the tetrahedra produces a charge imbalance imparting a negative charge to the structure. About 40 naturally-occurring zeolites have been described and over 100 synthetic zeolites have been made for industrial applications. The latter are commonly known by their commercial designation as "molecular seives."

The physical-chemical properties of the zeolite minerals are extremely variable. The mineral can easily be dehydrated and rehydrated; cations easily substitute and re-enter the structure; the ion exchange capacity and the ability to absorb various gases is enormous; an increase in the silicon to aluminum ratio decreases cation substitution, but increases acid resistance and thermal stability; the increase in silicon to aluminum ratios decreases cell dimensions and external pore diameters, further altering the nature of molecular interaction. The changes in physical-chemical properties of the zeolite minerals may affect their biological potential.

Zeolites naturally form by alteration of volcanic ash, which is essentially glass. This alteration may occur either in saline alkaline lake waters, or in areas where ground water is present and may percolate through the sediments. Alkalies present in the volcanic debris are dissolved and chemically react with the glass to form zeolite minerals. Zeolites naturally occur in volcanic sediments throughout the United States. (9) Some of the zeolite minerals are extraordinarily abundant and widespread. Karain and Tuzköy pose the question whether natural zeolite minerals found in the rocks and soils of Turkey, or in other areas of the world, possess the biological potential to induce mesothelioma and other disease.

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DISCUSSION ON ZEOLITES IN TURKEY

QUESTION (Dr. Rowe): Dr. Rohl, the mesothelioma that is prevalent in this area of Turkey, is it all pleural mesothelioma or is there also peritoneal mesothelioma?

ANSWER (Dr. Rohl): It is virtually all pleural mesothelioma. There are one or two cases of peritoneal mesothelioma, but these may have been largely overlooked because it is a remote, rural area of Turkey. Modern medical services are practically unavailable. The only people who come to Dr. Baris' chest clinic at Haceteppe University are those with serious pleural disease. Those with other diseases may go unobserved.

QUESTION (Mr. Dickinson): Yesterday, we heard that if you used asbestos cement on roofing tiles and then collected water in cisterns you tended to get asbestos fibers at times. You mentioned having taken samples of house dust and road dust as well as white wash. Since this is a desert area, essentially, water is a very scarce commodity, I would hypothesize that probably villages would tend to have one water source from which they would all drink. My question is whether the same water source was available for all the villages or whether in effect each one has a separate source and may be one of them was contaminated and the others not?

ANSWER (Dr. Rohl): That was investigated. Although there are two water sources, one well is the major source for the entire village of Karain, and no agents were found in the water. It was analyzed for both inorganic and organic contamination which might be responsible. Although asbestos fibers were found by one investigator this has not yet been confirmed.

REMARK (Dr. Wiley): I am from the University of Maryland. I would like to stand behind what Mac Ross has said. I think that the evidence is not at all conclusive that zeolites are the cause of the mesotheliomas. I would just like to point out that the sizes that you mentioned, less than 0.25 microns in diameter and 3 microns in length, are almost identical to the sizes of wollastonite particles that were presented in the previous study. So that if indeed it is a size and shape factor that is in the disease, we have a real contradiction in the evidence here.

REMARK (Dr. Rohl): We have a whole string of ifs, ands, or buts. No one said it is a simple question. It is going to take a lot of time. It is a very complicated analytical matter, and the interpretation of the results will also be very intricate.

REMARK (Dr. Langer): I wonder if I can add to this discussion. Perhaps some other data will help shed light on this subject. Mt. Sinai has a number of ongoing studies in our Laboratory which appear to indicate the following: fibrous erionite has produced tumors (mesotheliomas) in the bellies of mice. Mordenite fiber has not as yet. It produces pronounced scarring. This might have been predicted by their aluminum: silicon ratios. Some species of fibrous zeolites appear to be fibrogens, some possible carcinogens. Perhaps not all of the zeolite minerals will be shown to be active. We need more time and experiments to verify this.

We have also completed studies concerning the hemolytic potential of these various materials. Again, the aluminum: silicon ratio has some correlation with hemolytic potency. High silicon containing zeolites are cytotoxic. These compounds are membrane active. Some of these materials, because of their extraordinary cytotoxity, will not allow cells to live long enough to undergo mutation and transformation. Cancer will not be the outcome for these exposures.

There is a tremendous set of data that has been collected by the IARC consulting group in Wales (PRU-Llandough): Wagner confirmed the Turkish mesotheliomas; Fred Pooley confirmed the presence of zeolite mineral species; Peter Elmes confirmed the clinical diseases; Joe Skidmore, probably one of the best "dust" men in the world, went there and performed environmental measurements. When all of these data were collected and looked at as a body of knowledge, the following was found:(1) there occurs bonafide mesotheliomas; (2) in the environment there exists a series of fibrous minerals. They are zeolites; (3) the environmental measurements suggest the amount of fiber that is actually in air is very small. These fibers are again zeolites. Yet, what is the agent that is responsible for the mesothelioma? Can small amounts of zeolite fiber produce mesothelioma? We have done some work on the stucco that is used to whitewash the insides of the Karain houses. They are derived from many sources of rock and some of these sources may contain other mineral fibers. These may be agents of disease as well.

There are other possibilities as well: I think it is much too early for us to dismiss the possibility that a subspecies of erionite fiber may produce mesothelioma; there may be some asbestos in the area.

QUESTION (Mr. Mill): I am from the Cabot Corporation. A common alteration product of volcanic tuff is cristobalite which has biologic activity. Was there any cristobalite in this tuff to your knowledge?

ANSWER (Dr. Rohl): Yes. Cristobalite was described in some of the samples.

QUESTION (Mr. Mill): And I would like to ask another question that is not about Turkey. There is a very common zeolite mineral which to my knowledge is not fibrous, in the American West, and that is clinoptilolite, which is beginning to enjoy some commercial exploitation. Does anyone know if this has been found to cause health problems?

ANSWER (Dr. Rohl): No, I do not think that has been studied with reference to clinoptilolite. clinoptilolite does occur in the Turkish tuffs.

REMARK (Dr. Langer): I would like to add to this. We have looked at clinoptilolite in our membrane system and it is very active. It has a "hemolytic" index or hemolytic potency which is almost equal to that of quartz.

REMARK (Mr. Mill): Well, I'd like to make one other comment. Clinoptilolite apparently is nonfibrous, and I find it difficult to accept this Stanton hypothesis, as it is mentioned in the abstract, that it is the geometry of these particles that determine their problems.

QUESTION (Mr. Merryman): I am from the Dupont Company. I would like to ask Dr. Langer what was the difference between the zeolite minerals that did and did not produce mesotheliomas or tumors in the laboratory different in shape in addition to their difference in chemical structure?

ANSWER (Dr. Langer): I am from Mt. Sinai. There are marked differences between erionite and mordenite. Erionite tends to be more "asbestiform", if I can use that term, than mordenite. Mordenite tends to occur as long, flat, bladed crystals. If we were to look at its size distribution characteristics, and compare it with erionite, erionite would be more like an amphibole asbestos mineral, like amosite or crocidolite, whereas the mordenite would be more like anthophyllite. I add that amosite and crocidolite have produced mesotheliomas in human populations whereas anthophyllite has not.

Mordenite tends to have less aluminum in the structure; therefore it has less of the alkaline cations substituting in the structure. The erionite tends to interact more with polar compounds (this has been described in the literature extensively). Mordenite tends to be more a silicon-rich, more "siliceous" if you like, and tends to have chemistry more like quartz, or like the silica polymorphs. Mordenite produces scarring in animals; erionite produces cancer.

QUESTION (Mr. Merryman): I gather then, that there is both a surface size and a chemical effect possible. Can you expand on that? Does there tend to be any data that indicate that you can have a chemical effect independent of the size and shape effect?

ANSWER (Dr. Langer): Absolutely. The Stanton hypothesis suggests that any fibrous inorganic dust which reaches the mesothelial surface will induce a tumor response. Mesothelioma or fibrosarcoma may be produced regardless of the chemistry and of the composition of the fiber. Last night we had an extensive discussion of this in the Talc Session. We talked about different mineral fibers and whether or not each possessed certain inherent physical-chemical characteristics which would distinguish among them in terms of biological activity. I believe it is simplistic to assume that because a material is a "fiber" that there is some extraordinary power to induce tumors. I do not think that is so. For example, we know chrysotile degrades readily while in biological residence, and amphibole fibers do not. Amphibole fibers deliver a dose to target tissue which is the number of particles multiplied by the unit time in residence in those tissues. Amphibole unit dose delivered to tissue is therefore longer than for an equivalent amount of chrysotile. Investigators have studied the activity of degraded chrysotile and observed a markedly decrease of mesothelioma potency. Therefore, both a changed surface character and a degradation process both account for markedly decreased carcinogenicity. What we were seeing is that obviously fiber morphology is useful in terms in inhalation potential, in terms of penetrating the airways, in terms of deposition at the alveolar site. But once it is delivered to the target tissue, the response would be dependent upon the characteristics of the material itself.

QUESTION (Dr. Reeves): I am from Wayne State University. I have yet to hear a substantial answer to Malcolm Ross' comment, specifically the difference between these two communities that seem to have the same geological structure and the same availability of dust, and yet the startling difference in mesothelioma incidence. I think that might be quite significant. I also looked at your mortality or morbidity data. Am I correct in remembering that there were seven new cases of mesothelioma in a town of 3,000 every year?

ANSWER (Dr. Rohl): Seven.

QUESTION (Dr. Reeves): Seven cases. Now over a lifetime that would amount to something like 15 percent of the population, perhaps 20 percent of the population coming down with the single disease of mesothelioma. Now this is such a startling incidence that I just cannot understand that this could have remained undetected throughout history. This is one of the oldest inhabited areas of the world.

ANSWER (Dr. Rohl): And one of the most primitive, too.

REMARK (Dr. Reeves): No, it was not; today it is, but at a time of Alexander the Great and so forth --

REMARK (Dr. Rohl): They did not have pathologists then.

REMARK (Dr. Reeves): These were the most cultured regions of the world. I would have expected someone like Hippocrates to notice.

REMARK (Dr. Rohl): Maybe he did, but we have no record of it.

REMARK (Dr. Langer): Dr. Reeves, I believe the name Karain comes from the Turkish which means "pain in the belly". Karain has a peculiar folk legend which states that "anyone from Karain who develops a pain in the side, soon his shoulder drops and he dies." This is the classical clinical syndromė for mesothelioma. But you are quite correct. It has been noted for a very long time that people from this area died with these strange chest maladies. And you are also correct, that the incidence is quite extraordinary.

We find no differences between our data and those of Fred Mumpton from SUNY: the same fibrous zeolites are present in the soils and dusts of villages with mesothelioma, and those without mesothelioma. Again, it may be a special subspecies of erionite or the presence of other fibrous minerals of great biological activity. Yet, we are still examining these specimens very carefully. X-ray diffraction shows the same basic mineral population in both localities. But there may be some specific fiber that occurs in Karain that is different from those which occur elsewhere.

If you take "active sites" on the surface of zeolite minerals and you block them with certain cationic species, I can assure you they will not be biologically active. But those of you who know zeolites, who know how active these materials are, how well it binds with various cations, will understand how active these minerals can be. These are wonderful compounds. However, if you inhale these particles, their activity does not stop. The activity may go on, degrading proteins and denaturing proteins in young tissue.

QUESTION (Mr. Wideland): I am a geologist from the University of Minnesota. I have a medical question which I ask out of ignorance. Has your laboratory or any other laboratories attempted to identify the mineral species in lung tissue of these people who have died from mesothelioma?

ANSWER (Dr. Rohl): We are working on that. We collected lung tissues from patients of Dr. Barris' with mesotheliomas and we are investigating the types and amounts of the minerals in those tissues. That will be a very important factor in interpreting the results.

QUESTION (Mr. Wideland): In my casual reading of the medical literature there does not seem to be a discussion of the possibility of ever locating a specific fiber that you could pin down to having triggered a carcinoma. Is that out of the range of possibilities?

ANSWER (Dr. Rohl): Well, identifying likely candidates would be an important first step. After the likely candidate is identified, then further animal experimentation would have to be done to find out if it does produce the same disease.

QUESTION (Mr. Ross): A couple of points. First, I do not have the reference, but I believe that Pooley has identified fibrous zeolites. I have to refresh my memory, but I believe Karain, a very isolated town, is the town with a very high incidence of mesothelioma, of five or six a year. Tuzköy has much fewer cases. I do not have the number, but Tuzköy has much fewer mesotheliomas than Karain which is not quite as isolated a city as Karain is. But one of the things that intrigued me in the Baris reports, is that in all the deaths he reported not one, I believe, was lung cancer. The males smoked. Now if you look at asbestos-related disease you see a very high correlation in a cohort mesothelioma with lung cancer. With asbestos workers--you do not find them all dying just of mesothelioma or all dying just of lung cancer. It surprises me that there was no reported lung cancer in this group of individuals. I defer to the medical people, but would this suggest a hereditary implication?

Going back to what I said, it is all very fine to do some good straight science on this, but when you do a little bit of science and very poor science and then you rush out to an industry and say you are going to kill the workers because you are using zeolites in your refining process, when that zeolite happens to be a synthetic zeolite that is not fibrous, the whole work force is put into a paranoia. Zeolites are a very large mineral group. And most zeolites are not fibrous. One person got a hold of a newspaper article and said we can not have the missile sites in Nevada because it will dig up the ground and all the zeolites will come out. So the whole southwest United States is full of zeolites which I call evil rocks. And so we take a very preliminary scientific investigation and scare half the United States. I do not think that is being very wise, particularly when the zeolite industry is out here, and 90 percent of the industry is out for cleaning up our environment.

REMARK (Dr. Rohl): One thing that I forgot to mention, there is lung cancer in both Karain and Tuzköy. The men in Turkey smoke; both populations smoke. The women do not. But there is no difference in the rates of mesotheliomas among men and women.

CHEMICAL DETOXIFICATION OF ASBESTOS FIBERS

by

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ABSTRACT

Exposure to asbestos materials is associated with a variety of biologic responses which include ferruginous body formation, chronic fibrosing processes, and development of cancers. Formation of a ferruginous body is an early response of tissues to asbestos, and a variety of such bodies involving deposition of iron containing materials on the fiber have been described. One type of ferruginous body is formed by the deposition of inorganic iron on the fiber surface. Acting on the premise that the addition of ferric oxides or other metal oxides to asbestos would detoxify silicates and other toxic sites on the fiber, several metal micelle forms of asbestos, including chrysotile, amosite, crocidolite, and anthophyllite have been prepared. Biologic testing of iron micelle forms of chrysotile and amosite show that the treatment with iron salts decreases the cytotoxity of these forms of asbestos when compared with untreated materials. The treatment of chrysotile with an iron salt also decreases hemolytic activity and adverse effects on membrane permeability of cells. Testing of the iron treated chrysotile in a variety of applications using Grades ranging from AAA to 7 RF 99 in quality indicates that the treated asbestos retains desirable physical properties and can substitute for asbestos in all its current applications. The chemical treatment has been extended to show that metal oxides of cobalt, chromium, manganese, aluminum, and copper also add to an asbestos fiber.

Exposure to asbestos in the environment is associated with increased risk of developing chronic fibrosis in the lungs and two forms of cancer, bronchiogenic carcinoma and mesothelioma. Asbestos has been characterized as an unavoidably unsafe material, but its desirable physical properties including heat resistance, reinforcing strength, chemical resistance, flow characterization and versatility in applications including cements, boards, papers, textiles, friction materials and numerous other products has supported the continued and essential use of asbestos minerals. Considerable efforts have been made to find substitutes for the use of asbestos in its varied applications, but these efforts have met with limited success. Invariably, proposed substitutes do not measure up to the use of asbestos itself, or there are considerable costs that make use of the substi-

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tute prohibitive. One approach to this issue is to develop a substitute by chemical detoxification of asbestos fibers. The objectives of this report are to discuss the basis for chemical detoxification of the asbestos surface, to present initial results of in vitro tests of treated materials, and to discuss the effects of chemical treatment on the desirable attributes of asbestos.

The most hazardous asbestos fibers are those characterized as being deposited in the alveoli. Once deposited at critical tissue sites, asbestos produces a variety of responses including irritation of cells and tissues, increased oxygen consumption, formation of ferruginous bodies, chronic fibrosis, an increased risk of bronchiogenic carcinoma, and an increased risk of developing mesothelioma. In 1974,[1] I developed a hypothesis that these various responses to asbestos were related. Silicate groups on the asbestos surface were characterized as active sites for formation of ferruginous deposits, and the leaching of magnesium ions from the surface was identified as being involved in some of the toxic effects.

Figure 1, adapted from my paper in 1974,[1] summarizes the hypothesis concerning the relationship between exposure to asbestos, ferruginous body formation, chronic fibrosing processes, and carcinomas. A sequence of dependent events is thought to occur leading to increasingly adverse toxic effects. The underlying mechanisms are depicted as involving two independent pathways. In one pathway, after phagocytosis and fiber encapsulation, a ferruginous body is formed consisting primarily of substances containing ferric oxides, such as ferritin, hemosiderin, or inorganic ferric hydroxides. The driving force for deposition of ferric containing species is the presence of electronegative sites produced by formation of hydrated silicates on the asbestos surface. The removal of ferric ions in the formation of a ferruginous body requires the oxidation of ferrous ions to replace the ferric ions in solutions and to reestablish redox equilibrium. This results in an increased glycolysis as indicated by increased oxygen consumption by tissues exposed to asbestos. Excessive glycolysis leads to release of a fibrogenic factor characterized by Heppleston[2] as possibly a galactan. This factor induces an increased synthesis of elastic fibers such as collagen at tissues which are remote from the site of deposition of the asbestos fiber.

In Figure 2, the synthesis of collagen requires an oxidation of proline in protocollagen by molecular oxygen with reduction by a reducing cofactor to form hydroxyproline. This converts protocollagen to a more hydrophilic collagen and frees the RNA-template for continued production of protocollagen. Thus, continued release of a fibrogenic factor induced by increased glycolysis stimulates a chronic production of fibrous protein or chronic fibrosing processes.

In Figure 1, the significance of the chronic fibrosing processes is inhibition of reductases leading to asbestos acting as a cocarcinogen in producing bronchiogenic carcinoma. This decrease in the availability of reducing cofactors favors production of stable epoxides derived from toxic products of combustion, synthetic toxins or natural products. Another cocarcinogenic mechanism for producing an increased risk of carcinoma is the disruption of membranes by the mechanical irritation of cells and tissues. The resulting increase in membrane permeability would provide greater access for carcinogens and other toxic agents. Finally, another cocarcinogenic mechanism is by transport of a carcinogenic

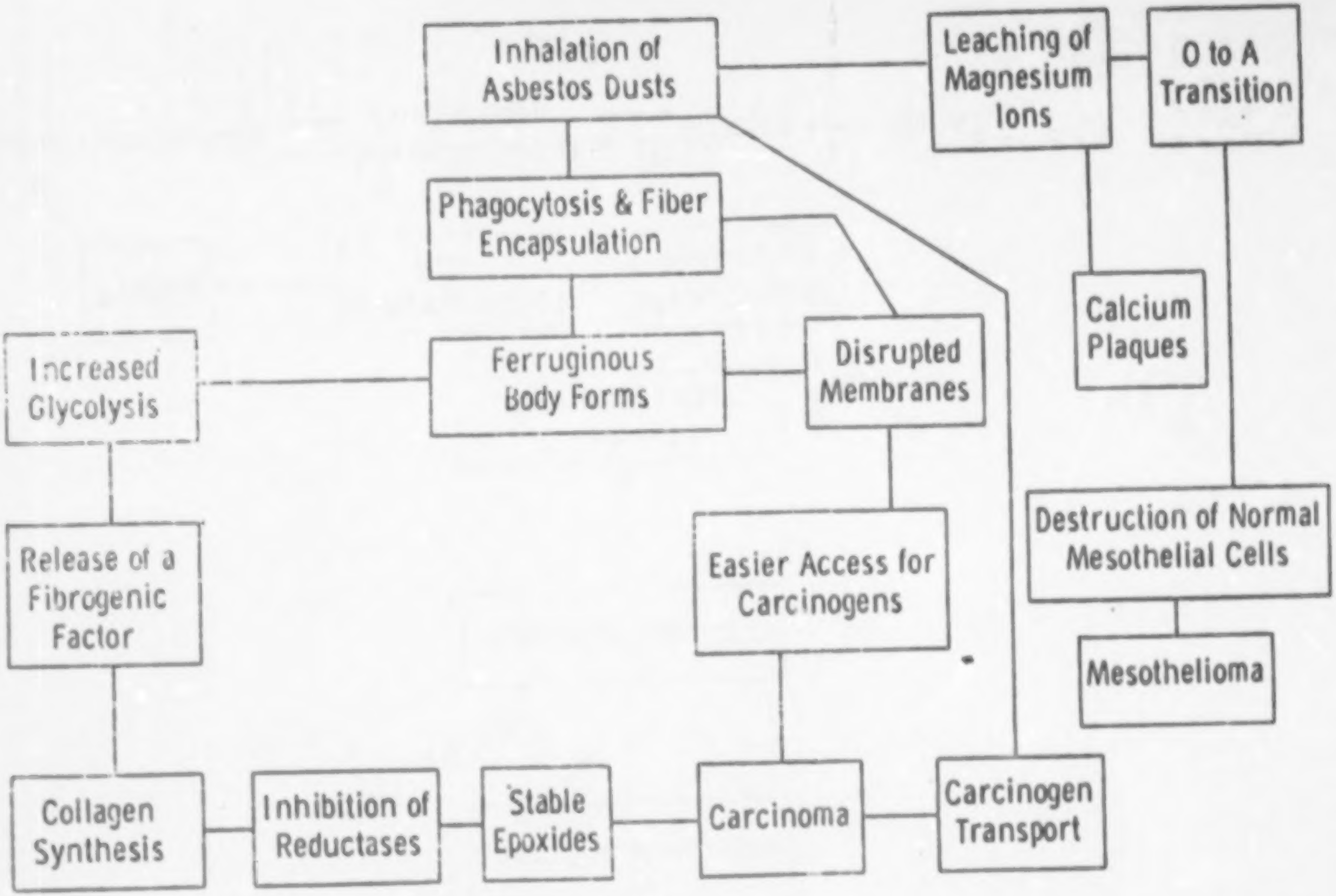
Inhalation of Asbestos Dusts
Leaching of Magnesium Ions
O to A Transition
Phagocytosis & Fiber Encapsulation
Calcium Plaques
Increased Glycolysis
Ferruginous Body Forms
Disrupted Membranes
Destruction of Normal Mesothelial Cells
Release of a Fibrogenic Factor
Easier Access for Carcinogens
Mesothelioma
Collagen Synthesis
Inhibition of Reductases
Stable Epoxides
Carcinoma
Carcinogen Transport

Figure 1.

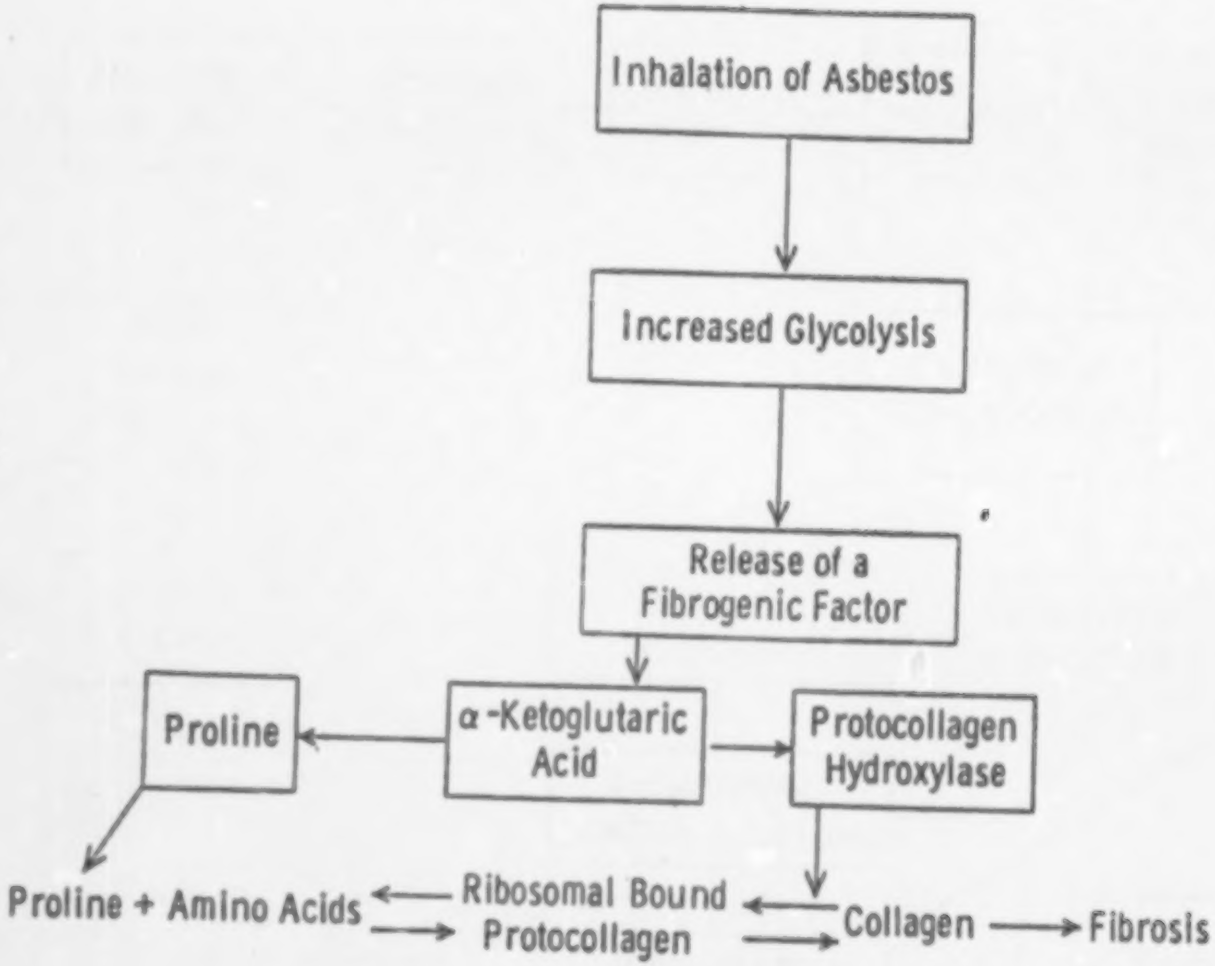
Inhalation of Asbestos
Increased Glycolysis
Release of a Fibrogenic Factor
α-Ketoglutaric Acid
Proline
Protocollagen Hydroxylase
Proline + Amino Acids
Ribosomal Bound Protocollagen
Collagen
Fibrosis

Figure 2.

agent to critical tissues on the highly active surface of an asbestos fiber.

Also in Figure 1, the leaching of magnesium ions from the asbestos surface is thought to interfer with solubility and ionic distribution of calcium. One manifestation of a disturbance in calcium metabolism is the formation of pleural plaques. Another manifestation is the induction of an orthodox to aggregate transition (O to A Transition) of mitochondria causing destruction of normal mesothelial cells. Surviving abnormal mesothelial cells could grow in an uncontrolled environment according to the bioenergetics and tumor growth theory described by Racker.[3]

Thus, a successful chemical treatment to detoxify asbestos depends on three principles.

1. Silicate binding sites must be masked by an agent that remains in place under physiological conditions.

2. Leachable ions such as magnesium must be removed.

3. The desirable physical attributes of asbestos such as strength, bulk density, surface area, magnetic properties, flow characteristics, heat, and chemical resistance must be essentially unchanged.

As an initial approach and assuming that the formation of a ferruginous body is an attempt to detoxify the absorbed asbestos, a proprietary process has been developed which prepares a highly saturated synthetic ferruginous body. The process involving iron uses readily available, relatively inexpensive raw materials, and chemical compositions of treated asbestos have been prepared using chrysotile, amosite, crocidolite, and anthophyllite. The treatment process has also been extended to produce chemical compositions of asbestos containing cobalt, manganese, chromium, aluminum, and copper.

Treated samples of amosite and chrysotile were tested for cytotoxicity using human lung macrophage cells in tissue cultures according to the procedure recommended by Wade, et al.[4]

Figure 3 is an example of the results using a UICC chrysotile B. In the test, cell cultures are allowed to grow for a 24-hr pre-exposure period. The cultures are exposed to the material under test for 48 hours. The media and most of the asbestos are removed, and the cells are cultured using fresh media for an additional 24 hours. Viable cells are counted at 24-hr intervals during the test, and five fields are counted for each culture. The upper curve shows the average number of viable cells in the controls, the next curve shows the average number of viable cells in cultures exposed to a treated UICC chrysotile B, and the bottom curve shows the average number of viable cells in cultures exposed to untreated UICC chrysotile B. The amount of asbestos in this series of tests was 100 micrograms/ml. Similar, but less dramatic results were obtained in tests using a treated amosite. From these results, the chemical treatment of asbestos decreases the cytotoxicity of the asbestos fiber to human lung macrophage cells.

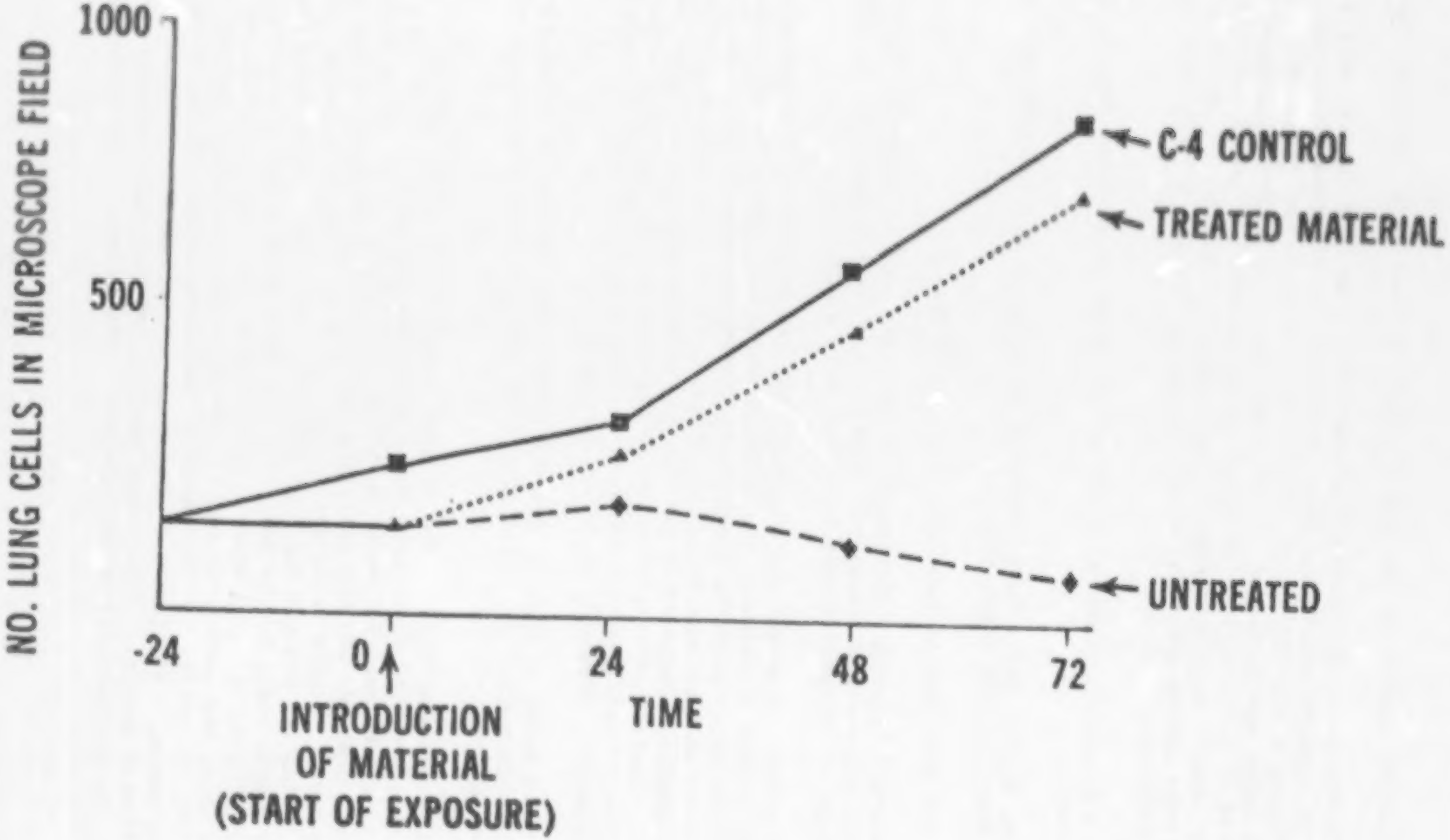

Figure 3. Biology: Initial data on cell viability -- UICC chyrosotile B.

Table I is a summary of physical attributes and differences caused by the treatment process. The magnetic rating decreases. This could be an improvement in the asbestos for certain electrical applications, but in other tests involving phenolic molding compositions, there is an increase in the preheating time. The magnesium oxide content decreases, and this is a desirable effect of the treatment. Color is dramatically changed. The disadvantage is that the color change may be unacceptable in certain products. An advantage is that the treated materials are readily identified. In cement formulations and phenolic resins, the color change is not a problem. The viscosity of a spinning solution containing AAA grade chrysotile decreases as a result of the treatment. A large scale test on a production line is needed to evaluate the impact of decreased viscosity on the quality of the textile produced. There is a decrease in cement strength at a high level of treatment, but no changes in cement strength were found at intermediate or low levels of treatment.

No changes in resin absorption, alkali resistance, acid resistance, and thermal insulation properties were produced as a result of treatment. The fiber milling and processing is changed to a wet process. Cytotoxicity shows a substantial decrease. The drainage rates of cement formulations decrease with increasing levels of treatment. A decrease in drainage rate may require changes in the drying, curing, and forming of asbestos cement products. In working with several grades of asbestos from AAA to 7RF99, a wet process tends to increase the surface area and to decrease the bulk density of longer fiber materials, but these changes may be attenuated by controlling contact time in the wet process and by more efficient dewatering. The treated asbestos materials compare favorably with the desirable attributes of raw or untreated asbestos.

In summary, initial biological data show that chemical treatment of asbestos to form a saturated synthetic ferruginous body decreases the cytotoxicity of asbestos to human lung macrophage cells. Physical test data indicate that desirable attributes of the fibers are retained. If additional in vitro and in vivo biological tests are successful in demonstrating a decrease in toxicity as a result of the chemical treatment and the performance of treated material is acceptable in products, this would allow treated fibers to serve as substitutes for asbestos in appropriate applications.

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TABLE 1. DIFFERENCES CAUSED BY TREATMENT

Magnetic rating	Decrease
Magnesium oxide content	Decrease
Color	Yellow, brown, blue, green
Viscosity of spinning solution	Decrease
Resin absorption	No change
Cement strength	No change except at high level of treatment
Alkali resistance	No change
Acid resistance	No change
Thermal insulation	No change
Fiber processing	Wet process
Drainage rate of cement formulation	Decreases with increasing level of treatment
Biological effect (cytotoxicity)	Substantial decrease

DISCUSSION ON CHEMICAL DETOXIFICATION OF ASBESTOS FIBERS

QUESTION (Mr. Taitenann): I am from Raybestos-Manhattan. I would like to raise the question about the use of the wet process. Could you describe the wet process to us, please?

ANSWER (Dr. Flowers): This may sound like blasphemy or a sacrilegious treatment of the asbestos fiber, but essentially, I make a slurry containing about 5 percent by weight of asbestos fiber, which would be about 95 percent by weight of water. There are two steps in addition to the treatment chemicals. The material is filtered initially and then put in a press. I have been using my wine press to dewater the asbestos. Then it can either be shipped as a wet cake containing about 30 percent moisture, or it can be dried and then fiberized.

I neglected to mention that in the laboratory scale operation, there are real problems with the wet process in terms of maintaining the desirable surface or bulk density of the material. I found, however, that in producing, say, a few grams of material I can control the contact time and the wet process. I can also filter the material fairly quickly and attenuate the possible adverse effects on enhancing or opening up the surface, which would make it unuseable in certain processes.

I can produce asbestos that is fairly equivalent in surface area by nitrogen permeability and such, but when I try to go to several pounds, tens of pounds, or hundreds of pounds, I have found that I just cannot scale up my laboratory to a reaction tank for this system.

So the wet process may be a problem and requires a lot more work.

QUESTION (Mr. Taitenann): One other question. You referred to viscosity in the spinning operation. What type of operation are you referring to there?

ANSWER (Dr. Flowers): Well, I am not very knowledgeable about textiles in the production of fibers, but Dr. Kunsey of the Ontario Research Foundation did the evaluation of the spinning property, and he said the viscosity changes, and to really know what this means you have to produce enough sample to put it in a production line and see what effect it has on that particular characteristic.

REMARK (Mr. Wright): I am from the Steel Workers Union.

Let me just make one historical comment. Let me first say that I think your research is very interesting, but I want to, perhaps, inject a note of caution about how readily it ought to be accepted.

First, I think that even if everything you say pans out, there are questions about the stability of the coatings in the environment.

and there are also, I think, some questions about the toxicity of various coating materials, especially things like manganese and possibly aluminum and chromium.

But let me make the historical comment, which is that back in the thirties, there was a lot of excitement about the idea that aluminum oxide therapy would be effective in protecting miners from silicosis. The idea was that if one went into the mines and then came out at the end of the day and breathed aluminum oxide fumes or dust for some period of time, the aluminum oxide would naturally coat silica particles in the lungs and thereby protect the miner. The therapy was based on two things: the first was some preliminary biochemical theories about the way silica dust acted in the lungs, the idea that one could encapsulate whatever the problem was by the aluminum oxide; the second was based on some very preliminary animal studies. Those studies were discredited within, I think, about 10 years, but nevertheless, based on the very preliminary work, the underground mining industry and a lot of foundries adopted this procedure. Many underground miners and foundry workers spent the last half hour or 15 minutes of their work day, depending on how it was done, breathing aluminum dust.

Some of those people may have long-term lung disease from that therapy, which was proven not to protect them against silicosis. That has been very well documented. As a result, the method was scientifically discredited by the late 1950s. In 1978 we discovered several mines in Northern Canada that were still using the therapy and we stopped it very quickly. And there may be more people out there who are still using it.

The point I am trying to make is that it is very easy to jump to conclusions about the effectiveness of a particular detoxification process, and there may be some who would do that as an alternative to cleaning up the work place. I am not saying this to discourage your research. I am saying it to discourage the too-rapid adoption of a method that is not yet proven. And I think if I were questioned by one of the workers who I represent, I certainly would not, at this point, say that treated asbestos should be considered any safer than untreated asbestos. Maybe with more research, but I think that will take a lot of additional work.

REMARK (Dr. Flowers): I agree with just about everything you said, although I cannot confirm your experience regarding aluminum oxide as therapy in prevention of silicosis. But I tried to be fairly careful in how I characterized the results of our initial biological tests. In my summary, I indicated that it is successful in some rather extensive additional biological in vitro and in vivo tests.

Also, if through process engineering and economics, we find that the material retains the desirable physical properties and will work in various industrial processes, then it could be accepted as a process for chemical treatment and detoxification of asbestos. From an economic and biological point of view I think that iron oxide, or various forms of it, is the only real treatment that will be acceptable.

There was somewhat of a chemical academic interest to extend the treatment to chromium or other transition metals to show that this is a general reaction across the transition metal group and also with amphoteric materials.

I agree that a lot more work needs to be done. In our communications with the EPA, they say that the tests, particularly the biological data, will have to be very persuasive for them to accept such a substitute. And that is not only for our material, but also for all the 60 or so materials that have been proposed as substitutes here over the last few days.

REMARK (Mr. Wright): I would like to make one final comment, not about what you presented, which I have no quarrel with, but about iron oxide. There are some questions about iron oxide itself being a cocarcinogen based on two things. One is some work that Saffiotti and others did, exposing, I think, Syrian golden hamsters simultaneously to iron oxide and a carcinogen. This showed a greater response when the iron oxide was administered along with the carcinogen than when the carcinogen was administered alone, even though iron oxide alone did not give any increased carcinogenic response.

Also there have been some epidemiologic studies in gray iron and steel foundries indicating an increased risk of cancer in those work places. We do not know what that is caused by, but one hypothesis is iron oxide, so you have to be careful.

REMARK (Dr. Flowers): Iron oxides are a normal waste product of oxidated metabolism in cells. The ferric hydroxide is sometimes viewed as the brown gelatinous amorphous material floating around in the cells, so essentially, the iron is something like that amorphous gelatinous material. However, from our X-ray defraction data, we have prepared a highly ordered form of this material, using the asbestos surface as template for its precipitation and formation.

QUESTION (Dr. Patel): I am from the New Jersey State Department of Health. I have three questions. One is what happens in your lung cell tests beyond 72 hours after treatment. The other is what happens to the acoustic properties of asbestos. Finally, is this process useful only in the manufacturing aspect of asbestos or could it be used after the product has already been manufactured, for example, in school ceilings? Can you treat the manufactured product so that it will penetrate further and not only remain on the surface?

ANSWER (Dr. Flowers): We do not know what happens after 72 hours because the test protocol stops after 72 hours. This is a short-term assay to evaluate the initial biological response.

We do not look at acoustic properties. Ontario Research can make test panels and measure the acoustic properties, but that was one test we did not look at.

The process is essentially a technique for contacting the asbestos surface with a solution of treatment chemicals. Depending on your degree of imagination, you could contact the exposed asbestos at the mine with the treatment chemical. I claim that you could develop devices for contacting asbestos wherever you find it, including those asbestos fibers which are already present in the lungs of people who have been exposed, thereby providing a synthetic process for deriving a synthetic ferruginous body from an exogenous source of ferric salts.

REMARK (Dr. Cooper): I am from Berkeley. I wanted to make a comment on the remarks of the Steel Workers' representative. I certainly agree with him and with Dr. Flowers that something like this has to be studied and approached very cautiously and certainly is not a substitute for industrial hygiene.

I do not think that the analogy with aluminum and silicosis is quite applicable here. There is very good biologic evidence that aluminum and iron do modify the fibrogenic potential of silica; that has not been, shall we say, discredited. The thing that has been discredited is the inappropriate application of aluminum and iron to the prevention of silicosis. Substituting the addition of inhaled aluminum powder for adequate dust control has been justifiably discredited. Since it was clearly impossible to coat with aluminum the quartz particles that resulted from drilling a hole in a hard-rock mine, the effort was made to coat them after they got into the body. Although I think it is a difficult path that has to be followed to establish these things, I do not think that that analogy should be used to discredit this type of approach.

QUESTION (Mr. Wilkin): I am with Dresser Industry. The three criteria that you provide for detoxifying the fibers are: removing the magnesium oxide surface, ensuring the surface is stable to alkaline conditions, and maintaining the same strength and flow properties of the resultant material. Do you have any comments on the other methods of doing this, such as the acid leaching and organosilane or sodium silicate treatments that are currently patented?

ANSWER (Dr. Flowers): I was very interested in the Dow patents, for example, involving the molybdate and tungstate treatment. They used a Grade 7 chrysotile and showed that hemolytic activity could be decreased up to 100 percent by treating the surface with the molybdate and the tungstates. They used a wet process. I think they also removed some of the brucite or the magnesium oxide associated with the surface. The metallic tungstate and molybdate salts are alkaline resistant, so I think it does not violate the three principles that I have enunciated.

The heat treatment of asbestos actually drives off hydroxide by hydroxide reaction or oxidation with oxygen. This gets rid of hydroxyl groups. I think that when you hydrate or rehydrate silicate bonds you may have some problems once they are deposited in a physiological system.

One other treatment used is the removal of magnesium oxides and other metals by moderately strong acid treatment of the surface. According to the paper presented in May, by Marcelle Cahette, at the Fourth International Conference on Asbestos in Italy, they have successfully demonstrated decreased cytotoxicity and decreased release of enzymes from membranes and also decreased hemolytic action of the chrysotile asbestos, which had been subjected to the moderate acid treatment.

So, yes, there are other approaches. My approach was to mimic what I consider to be a detoxification attempt by the body and to make a synthetic ferruginous body.

QUESTION (Mr. Wilkin): Would your studies also include the possibilities of detoxification by the reaction of the surface with an organosilane to make the surface hydrophobic?

ANSWER (Dr. Flowers): I cannot comment on that one way or the other, but I really have not given any thought to that particular process.

REMARK (Mr. Wilkin): There are a few applications for asbestos that would probably best be served by a hydrophobic coating rather than a hydrophilic coating.

REMARK (Dr. Flowers): I do not want to make my process mutually exclusive of other processes. I think there is probably room in the substitute field for many products.

REMARK (Dr. Gross): I am with the Industrial Health Foundation. If phagocytosis to these treated fibers does take place, then we are up against another facet that contradicts the present theory of the pathogenicity of asbestos, namely, the theory that incomplete phagocytosis of the asbestos fiber causes leakage of intracellular enzymes into the surrounding medium and, consequently, into the surrounding tissues. The leakage of these intracellular enzymes would then cause tissue damage and, ultimately cancer.

If your demonstrated lack of cytotoxicity by the treated asbestos fiber takes place in spite of phagocytosis, then this theory falls into the ash can, and we do not have a viable theory for the pathogenicity of asbestos. Our concern for the substitutes for asbestos, like man-made vitreous fibers, also should be abated because this concern is based on the theory that the geometry of the fiber in great part is responsible for the pathogenicity of fibers.

It is agreed that the geometry of a fiber is responsible for the fiber landing at the target site, but if this theory about leakage of intracellular enzymes into incomplete phagocytosis is destroyed, then we should not have any concern for the pathogenicity of manmade fibers.

QUESTION (Dr. Bernstein): I think Dr. Gross's comments are well taken. I would like to ask you, along the same lines, did you do size measurements of your fibers, and if you did, did you do it before they were treated and after they were treated, and what sizes were they?

ANSWER (Dr. Flowers): Yes, we have rather extensive data, both the light microscope and the electronmicroscope data on the size distribution of the fibers and the effect of treatment on size.

There is a slight increase in average diameter after treatment, compared to before treatment.

QUESTION (Dr. Bernstein): What were the figures?

ANSWER (Dr. Flowers): I do not have the figures with me.

QUESTION (Dr. Bernstein): What about the length? Did you look at length?

ANSWER (Dr. Flowers): No. I used Grades Triple A chrysotile, Grades 4 and 5 chrysotile, Grade 7 type purity, Grade 7 RF 99, and these go from extremely long materials to extremely short fine fibers.

REMARK (Dr. Bernstein): Well, I think it is important to point out that the effects you have shown could be explained by either a change in diameter, an increase in diameter, perhaps, or a decrease in diameter and/or length. And until that is straightened out and put on the record, it is really unfair to interpret the results.

QUESTION (Dr. Flowers): What percentage change would be significant, in your opinion?

ANSWER (Dr. Bernstein): I could not venture a guess until I saw your results and I do not know if I could venture a guess after that until I have seen the experiment.

REMARK (Dr. Flowers): There is less than about a 5 percent change in diameter and no change in length.

We mainly took pictures sufficient to count the cells, but not to evaluate whether phagocytosis was going on. So that is an omission.

In the protocol that we followed, we primarily were interested in seeing if we could demonstrate a decrease in cytotoxicity and that was the one issue we looked at. We did not look at some of these other issues, which now seem to be more important, or assuming more importance.

REMARK (Dr. Bernstein): Relating to Dr. Gross's comments, I think if you can demonstrate that the phagocytes are ignoring your coated fiber (and you probably could do that using the methods that we saw from the Brookhaven National Laboratory), you might be able to support your findings a lot better.

REMARK (Dr. Flowers): We do not make any claims that this is the only test that we are going to run. As a matter of fact, this afternoon I am going to talk about criteria for acceptable test protocol for evaluating proposed substitutes. This was based on an unofficial request to EPA under Section 4(g) of TSCA, as a petition for acceptable test protocols for evaluating and, subsequently, if successful, registering a product for use. We do plan more extensive *in vitro* and *in vivo* tests.

HEALTH CONSIDERATIONS IN THE PERLITE INDUSTRY

by

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ABSTRACT

Commercial perlite is a naturally occurring glass of volcanic origin which, when heated, expands to form a product of low density, high surface area, and low thermal conductivity. Expanded perlite is used in thermal insulation as a filter aid, as an inert carrier and filler, and as a soil conditioner. Perlite is a noncrystalline silicate. Most ores and products contain less than 1 percent quartz or cristobalite, although there are commercial deposits with as much as 5 percent quartz.

Studies in animals reported in 1953 showed no evidence of pulmonary fibrosis. Nevertheless, most major producers and processors provide periodic chest films. A review of films in 240 perlite workers which was reported in 1975 showed no evidence of pneumoconiosis associated with perlite exposures: however, only 28 of those studied had been in the industry for 15 years and only 7 for 20 years. A recent updated review, which involved 43 men with 15 or more years in the industry and 18 with 20 or more years, again showed no evidence of perlite-related pneumoconiosis. Pulmonary function in 117 perlite workers was studied in 1975; there was no decrement in forced vital capacity. There was slight, but not statistically significant, reduction in average forced expiratory volume. An updated review of pulmonary function is now underway; preliminary findings do not indicate a significant effect from perlite. Current recommendations are that perlite be regarded as a nuisance dust except in products with 1 percent or more crystalline silica.

INTRODUCTION

Perlite is a naturally occuring noncrystalline silicate of volcanic origin which expands when heated to form a product of low density, high surface area, and low thermal conductivity. It is not fibrous. The principal end uses of expanded perlite are filter aids, construction aggregates, horticultural aggregates, acoustical tile and insulation products. It can be regarded as an asbestos substitute in only a limited sense, as in some specialized insulation materials. The principle competitive commodities are vermiculite, pumice, slag, diatomite and expanded clay and shale.

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The perlite industry has a comparatively short history, the commercial possibilities of the material not having been recognized until after World War II. Production in the United States began in 1946; there are now 13 mines in 6 western states, with New Mexico accounting for 88 percent of the total output in 1979. In that year processed perlite sold or used in the United States totalled 650,000 tons.

Mining of perlite is by open pit. Although expansion is carried out by some producers near the mining sites, it is a common practice to ship the crude ores to expanding facilities near points of distribution.

Expansion is carried out by injecting finely divided crude ore into furnaces fired by gas or oil, where temperatures are maintained in the range of 1400 to 2000°F (760-1100°C). The 2 to 5 percent combined water in the crude ore causes the particles to "pop" or expand, producing a product with a bulk weight of 3 to 12 pounds per cubic foot, compared to a bulk weight of 65 to 75 pounds per cubic foot for crushed and sized crude perlite ore. After expanding, the particles are classified by size prior to shipment or use.

DESCRIPTION OF PRODUCT

Perlite ores and expanded perlite are largely aluminum silicate, in a noncrystalline, nonfibrous form. Some perlite ores contain small amounts of crystalline silica; i.e., quartz, but most do not. For example, analyses of several samples by the Bureau of Mines in 1956 showed quartz concentrations ranging from less than 1 percent to 3.0 percent. Other analyses in 1971 by McCrone Associates showed quartz concentrations ranging from under 0.5 percent to 5.8 percent in ores, and from 0.5 percent to 5.2 percent in expanded perlite. In 1979, five ores and resulting products were analyzed for the Perlite Institute. Quartz and cristobalite concentrations were measured in the ores and products, and in total airborne dust and respirable dust. In most, quartz was below detectable range; the highest concentration in respirable dust, from one product, was 1.7 percent. In no case did cristobalite exceed 1 percent.

The potential for dust exposures in the perlite industry are those of any operation in which there is open pit mining, crushing, screening, and loading of ores, and the subsequent production and handling of a finely particulate product. Those who use expanded perlite in the manufacture of various end products are of course also subject to potential dust exposures.

There are no published figures on airborne concentrations of dust in the perlite industry, but available unpublished data indicate that nuisance dust levels are easily exceeded during some operations, such as bagging or cleanup, unless precautions are taken.

BIOLOGIC EFFECTS

In 1953 Vorwald[1] et al reported no evidence of fibrosis following intratracheal injection of 0.5 percent of a 5 percent suspension weekly in guinea pigs for 3 weeks. Nine products were tested. One product was tested by inhalation in guinea pigs and rats over a period of 18 months with an average dosage of 590 mppcf (6.4 mg/ft^3 or 226 mg/m^3). No significant pulmonary reaction was observed. Schepers[2] subsequently reported that the inhalation of high concentrations of perlite appeared to stimulate the progression of experimental tuberculosis in guinea pigs. Infections, however, became arrested several months after exposures stopped. The exposures were extremely high, being maintained for 8 hours a day, 5-1/2 days a week for 6 months at average concentrations of 582 mppcf with 50 percent to 80 percent in a respirable size range. On a weight basis, exposures averaged 8.03 mg/ft^3 or 284 mg/m^3.

STUDIES IN EXPOSED POPULATIONS

Advisors to the perlite industry in 1953 recommended that perlite producers and expanders maintain medical surveillance of exposed workers and not permit unrestricted dust exposures. These programs have made available files of chest radiographs which in recent years have become useful to determine if there has been any evidence of pneumoconiosis.

The first published review,[3] supported by a contract from the Perlite Institute, Inc., involved films taken through 1974 (Table 1). Records were obtained on 100 men identified as working in perlite mining operations and 185 in expanding operations. The latter offered opportunities for exposure either to crude or expanded perlite. Films were obtained on 240 individuals. One individual found to have simple pneumoconiosis and one with complicated pneumoconiosis had formerly been employed in the diatomaceous earth industry, one for 13 years, the other for 24 years. Because only 28 of those studied had been employed for 15 or more years in perlite, and only 7 for 20 or more years, the results were regarded as preliminary. It was concluded that continued surveillance was essential to make sure that there are no effects with more prolonged exposures. Studies of pulmonary function of individuals with relatively long exposures were recommended.

An updated radiographic review was carried out in 1979[4] (Table 2), in which 6 of the 10 plants which participated in the 1974 study took part. These six plants had furnished over 90 percent of those included in the first study. The study was limited to men with 5 or more years in the industry. There were 130 individuals whose films were reviewed; 93 of these had been included in the 1974 study. Of the participants, 46 were from plants which mined and shipped crude perlite; 62 were from an operation where perlite was mined and also expanded, while the remaining 22 were from plants where crude perlite was expanded. Table 2 summarizes the film interpretations, based on readings by radiologists certified as B readers. Table 3 provides details on the four individuals interpreted as positive for pneumoconiosis. There still appears no pattern of disease associated with working with perlite.

PULMONARY FUNCTION

In June 1975 pulmonary ventilatory function was studied in 117 men employed in three plants engaged in the mining or processing of perlite.[5] Forced vital capacity and forced expiratory volumes in one-second were determined using a 9-liter Collins spirometer and a model II Jones Pulmonor. A detailed summary of the findings was reported in November 1976. Forced vital capacity measurements did not show reductions that correlated with length of exposure.

TABLE 1. FILM INTERPRETATIONS IN PERLITE WORKERS
(1974 Survey)

Years in the Perlite Industry	No. of men with films	Changes consistent with pneumoconiosis		
		Negative	Doubtful	Positive
0- 4	106	105	1	0
5- 9	52	50	1	1[a]
10-14	54	52[b]	1	1[c]
15-19	21	18	3[d]	0
20-24	7	6	1[e]	0
Total	240	231		2

[a] Complicated diatomite pneumoconiosis (24 years in DE).

[b] One with residual of pneumonitis.

[c] Simple diatomite pneumoconiosis, exposure approximately 13 years.

[d] One with exposure to diatomaceous earth.

[e] One with exposure to diatomaceous earth.

TABLE 2. FILM INTERPRETATIONS RELATED TO YEARS IN THE PERLITE INDUSTRY (1979 Survey)

		Changes consistent with pneumoconiosis					
		Negative	Doubtful		Positive		
Years	No.	(0/-0/0)	0/1	1/0	1/1	2/2	3/3
5- 9	54	49	1	2	1	-	1[a]
10-14	33	28	2	3	-	-	-
15-19	25	21	1	1	2	-	-
20-24	13	11	2	-	-	-	-
25-29	5	4	-	1	-	-	-
Total	130	113	6	7	3	-	1

[a] Present in pre-employment film 1966, interpreted as pleural changes at that time.

TABLE 3. FILMS INTERPRETED AS POSITIVE (1/1 or greater)

No.	Classification	Age	Years	Jobs	Comments
1	1/1	48	5	truck driver	no previous film
2	1/1	54	17	bulldozer op. truck driver	no change since 1967
3	1/1	48	18	mobile eq. op. maint. mech.	slight change since 1960
4	3/3C	61	9	general worker (6 years) grizzly op. maint. mech.	called pleural changes in 1966 and 1974. Term: 1975; died 1976 (no autopsy)

There were slight reductions in FEV_1 and in the FEV_1/FVC ratio. Although these could not be entirely explained by cigarette smoking and were associated with number of years in the perlite industry, the reductions were not statistically significant beyond the 0.1 percent level.

The major producers of perlite continue to maintain a program of periodic chest films and since 1975 have provided annual testing of pulmonary ventilatory function. An analysis of later pulmonary function results obtained during 1977, 1978, and 1979 is now underway; preliminary indications are that there is no evidence of a systematic reduction of function associated with perlite exposure.

SUMMARY AND CONCLUSIONS

There is no evidence to indicate that individuals engaged in the mining, expansion, or use of perlite develop pneumoconiosis. Nevertheless, it is recommended that there be strict adherance to nuisance dust levels, assurance that quartz levels are never excessive, periodic medical surveillance, and retention of records and chest films for periodic reevaluation.

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4. Cooper, W. C. Review of Chest Radiograms of Perlite Workers, preliminary report presented at 31st Annual Meeting of Perlite Institute, Inc., April 22, 1980.

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DISCUSSION ON PERLITE

QUESTION (Dr. Langer): I am from Mt. Sinai.

Is the silica present in this material as discrete particulates or does it have crystalline domains and are the surfaces a little bit greater? In other words, if there is a 1 to 10 silica content, does it mean 1 percent is discrete particles. Do you have more exposed silica surface?

ANSWER (Dr. Cooper): I do not know and I am not sure that that is known. I think that it is more or less a contaminant associated with the ore body, but I do not know.

REVIEW OF THE HEALTH EFFECTS OF MICAS

by

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ABSTRACT

Available literature on locations, characteristics and uses of micas is briefly discussed.

Available world literature on bioactivity and pneumoconiosis attributed to micas is reviewed. An attempt is made to separate cause-effect relationships according to the type of mica causing the exposure or used in the experiment. Insufficient data were found to make the distinction. Electron microscope photographs of micas from various sources are enclosed.

According to Petkof in his chapter on mica in the compendium "Industrial Minerals and Rocks" mica or micas are predominately potassium, aluminum silicates with varying amounts of magnesium, iron, lithium and some other trace metals.[1] These minerals have layered lattice-type internal structure, with tetrahedral grouping of oxygen atoms surrounding silicon atoms or aluminum atoms. Tetrahedral groupings result in pseudohexagonal network within a plane. The double or mirror image network is superimposed on the "peak" side of the tetrahedron and the two layers are joined by hydroxyl groups or metallic ions such as aluminum, magnesium, or lithium. These double layered structures are joined by potassium atoms. The potassium atom locations constitute the cleavage plane of mica. The American Conference of Government Industrial Hygienists defines micas as "nonfibrous silicate occurring in plate form" including nine different species.[2]

Distribution of micas is probably worldwide. It is found both in metamorphic and igneous rock. The decomposition of such rock produces sand and clay and introduces finely ground mica into our environment where it is naturally distributed by wind and water the same way as any other mineral. In relation to man this condition must have existed throughout the history of mankind.

However, let us get back to science. When we consider the idealized chemical structures of the complete crystal, it becomes obvious that muscovite and phlogopite appear structurally more uniform than biotite. (Fig. 1) These two

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Idealized Mica Formulas

MUSCOVITE COLORLESS – $K_2\ Al_4\ [Si_6\ AL_2\ O_{20}]\ [OH, F]_4$

PHLOGOPITE COLORLESS TO BROWN – $K_2\ (Mg, Fe^{+2})_6\ [Si_6\ Al_2\ O_{20}]\ [OH, F]_4$

BIOTITE BLACK, BROWN, GREEN – $K_2\ (Mg, Fe^{+2})_{6\text{-}4}\ (Fe^{+3}, Al, Ti)_{0\text{-}2}\ [Si_{6\text{-}5}\ Al_{2\text{-}3}]\ O_{0\text{-}2)}$ $(OH, F)_{4\text{-}2}$

Figure 1.

are the predominant commercially used micas. Muscovite probably accounts for about 90 percent of the mica used in the world. This became quite obvious during the literature search.

This approximate schematic does not lay claim to perfection; (Fig. 2) it does depict approximate possible paths of conversion from one mineral to another over a long period of time. Other paths may be entirely possible because there is one concept in geology that is absolutely true--for every rule and generalization there are numerous exceptions.

I would like to call your attention to the term "pegmatite." It really refers to the structure and not to the composition of this particular granite variety. Returning to the economically important micas, namely muscovite and phlogopite, it is important to note that almost all of the muscovite recovered in the United States is a co-product or by-product in quartz, feldspar, kaolin and perhaps garnet recoveries, or vice versa. Consequently the impurities of that nature could be expected in the commercial grade micas. Sericite, which is a hydrothermal disintegration or weathering process end product or possibly a direct result of metamorphosis, contains considerable amounts of free silica. Even though on occasion cited in the literature as a mica, it should be considered as part of the clay family, at least for commodity purposes. One author claims that pure mica dust in the lung is less fibrogenic than a mixture of mica and free silica.[4]

The main commercial products of micas are sheet mica, scrap or flake mica and ground mica. Sheet mica, both muscovite and phlogopite, is found visually and hand-picked from the mined matrix rock. The sheets are hand separated in a way similar to separating pages from a wet book; the same material can be sold also in "block form." The value of sheet mica depends on size, clarity, color and in some occasions on the dielectric properties. In ground micas, depending on the end use, other properties may be important.

The leading manufacturers of sheet mica (splittings and block) in the world are India, Brazil and Malagasy. Sheet mica is used primarily in the manufacture of electrical appliances, vacuum tubes, electronics and capacitors. From a physiological and perhaps health standpoint, the scrap, ground and flake mica is more significant. (Fig. 3) The United States is still the leader in scrap, ground and flake mica production. Looking at the 1977 data reported by U.S. Bureau of Mines, one can see the distribution of end-products according to standard industrial classification codes.[5]

The following map (Fig. 4) shows the counties in the United States in which mica is produced for commercial purposes. The consuming states are again not particularly widely distributed. Over 80 percent of U.S. block mica and film used in fabrication is consumed in New York, Pennsylvania and Virginia. North Carolina, Massachusetts, and Ohio are the other consuming states.

Ground mica in 1979 was produced in Alabama, New Hampshire, New Mexico, North Carolina, Pennsylvania, South Carolina and South Dakota. The same states also produced mica flakes. Mica flake was also produced in Connecticut and Georgia. When export and import data are considered, United States exports and imports about 6 million pounds of mica each year. For comparative purposes,

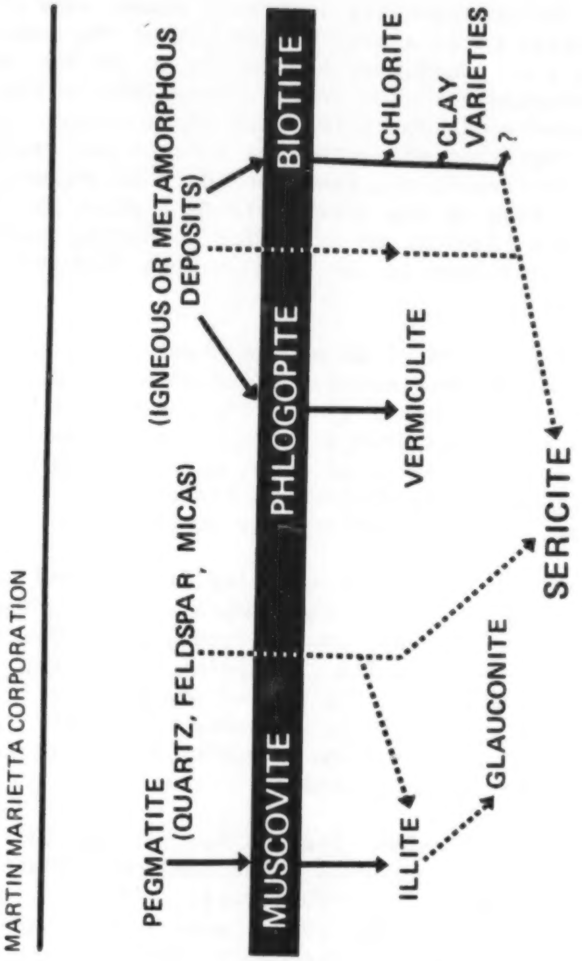
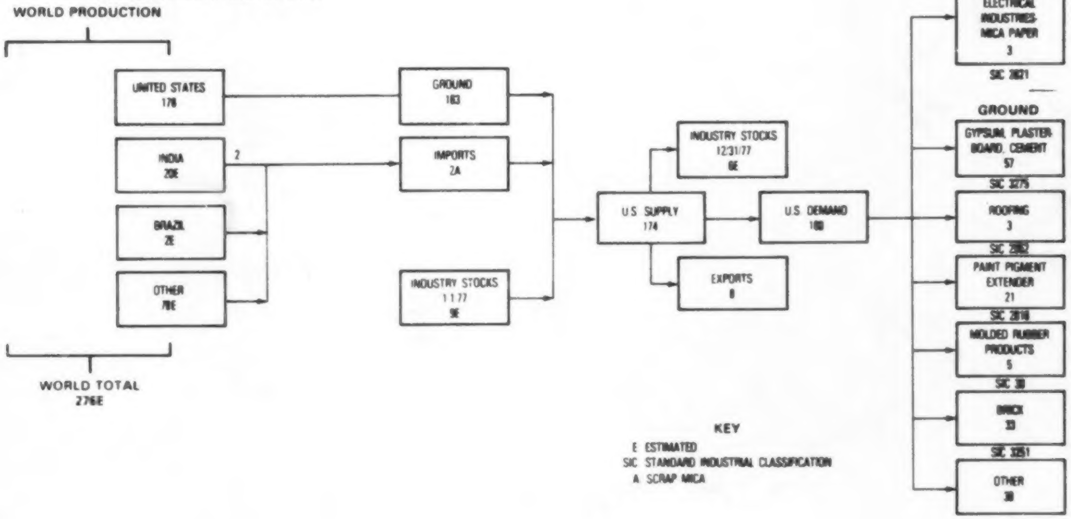

MARTIN MARIETTA CORPORATION
PEGMATITE
(QUARTZ, FELDSPAR, MICAS)
(IGNEOUS OR METAMORPHOUS DEPOSITS)
MUSCOVITE
PHLOGOPITE
BIOTITE
ILLITE
GLAUCONITE
SERICITE
VERMICULITE
CHLORITE
CLAY VARIETIES
?

Figure 2.

MARTIN MARIETTA CORPORATION

Mica (Scrap and Flake)

SUPPLY-DEMAND RELATIONSHIPS-1977
THOUSAND SHORT TONS OF MICA


WORLD PRODUCTION
UNITED STATES 178
INDIA 20E
BRAZIL 2E
OTHER 76E
WORLD TOTAL 276E
2
GROUND 163
IMPORTS 2A
INDUSTRY STOCKS 1 1 77 9E
U.S SUPPLY 174
INDUSTRY STOCKS 12/31/77 6E
EXPORTS 8
U.S DEMAND 160
DELAMINATED
ELECTRONIC AND ELECTRICAL INDUSTRIES-MICA PAPER 3
SIC 3621
GROUND
GYPSUM, PLASTER-BOARD, CEMENT 57
SIC 3275
ROOFING 3
SIC 2952
PAINT PIGMENT EXTENDER 21
SIC 2816
MOLDED RUBBER PRODUCTS 5
SIC 30
BRICK 33
SIC 3251
OTHER 38
KEY
E ESTIMATED
SIC STANDARD INDUSTRIAL CLASSIFICATION
A SCRAP MICA

BUREAU OF MINES
U.S. DEPARTMENT OF THE INTERIOR

Figure 3.

MARTIN MARIETTA CORPORATION

Mica Mining Counties (including Sericite) In U.S.A./Spring 1980

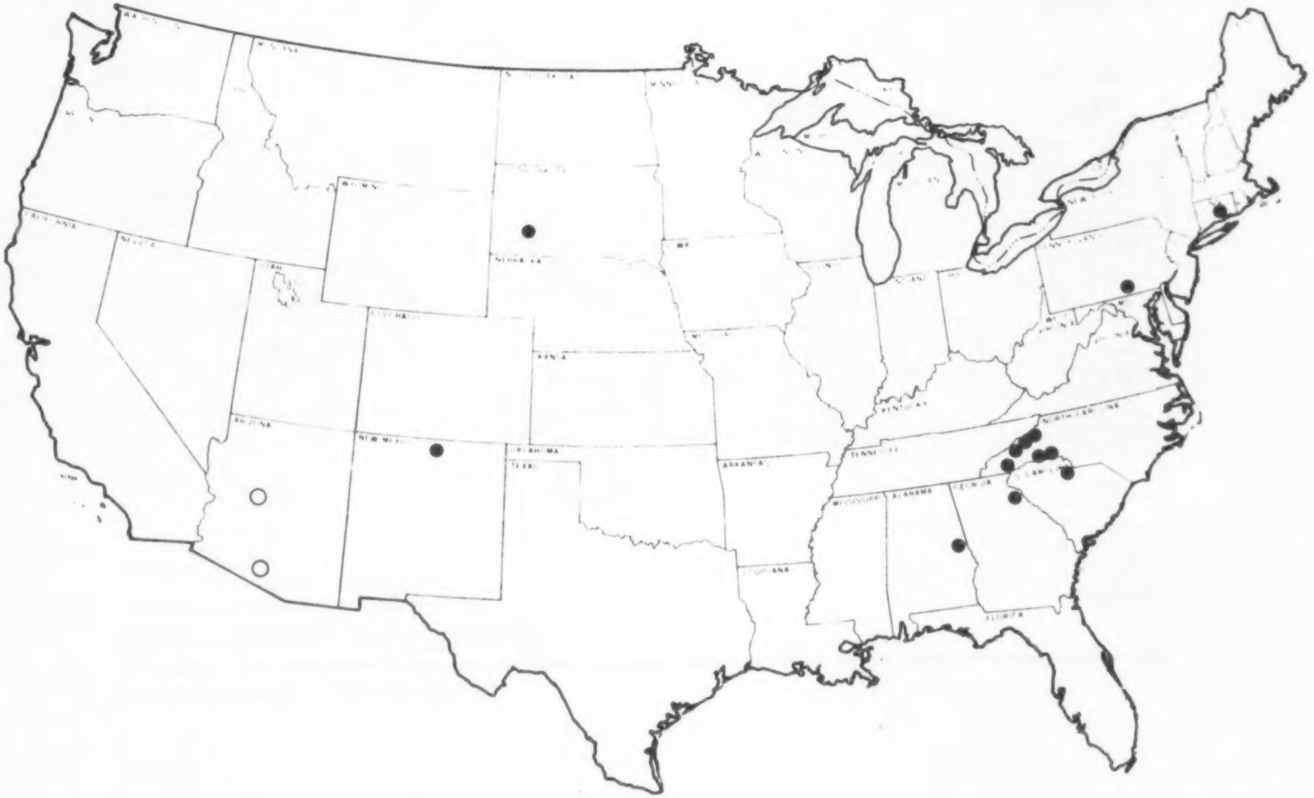

KENTUCKY
NORTH CAROLINA
TENNESSEE
ARKANSAS
MISSISSIPPI
ALABAMA
FLORIDA

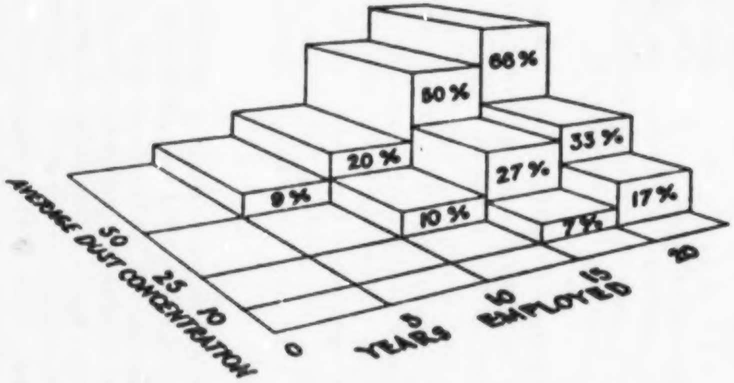
Figure 4.

the total world production of micas in 1978 was 533 million pounds. In 1979 it dropped to 528 million pounds.[6] These estimates do not include the production of such countries as Rumania. U.S. consumption of sheet and scrap or ground mica at the same time was 5.1 million pounds of sheet and 244 million pounds of ground mica. The production of mica paper should be noted as possible means of substituting sheet mica.

However, geology, geographic distribution and economic usefulness of mica is not the title of this paper. In the search of the health effects of micas, as the title of the paper would indicate, it is difficult to establish a starting point. In 1933 in the Journal of Indusrial Hygiene, W. R. Jones reported finding sericite in silicotic lungs and proposed the sericite crystals as the causative factor in pulmonary silicosis. In May of 1934, A. Policard from the University of Lyon in France reports on his animal experimentation involving finely ground "white mica dust," to which he subjects test animals in substantial doses for four hours a day, sacrificing them after three, five, sixteen and thirty days of exposure. He concludes that the lung changes have occurred, namely that "the altered cells are grouped in plaques in the alveoli. About them the pulmonary histocites gather, the aggregate forming a sort of mica granuloma."[7] His experimental evaluation techniques were limited to an optical microscope. The paper, unfortunately, does not state the dust concentration to which the animals were subjected.

The next significant publication chronologically is the almost classic study by Dreessen, Dallavale and others, entitled "Pneumoconiosis Among Mica and Pegmatite Workers," also known as U.S. Public Health Bulletin No. 250.[8] This study has served as a basis for threshold limit value determination of mica dust in the United States. Some of the airborne dust concentrations reported in the study were extremely high, such as kiln drying and manual bagging of mica, averaging 116 million particles per cubic foot and crusher dust ranging from 40 to 1,000 million particles per cubic foot. These values would apply to mica mining and recovery. Wet mica grinding operations ranged between 3.1 million particles per cubic foot and 158 million particles per cubic foot in the drying stage.

Mica fabricating, such as mica sheet trimming, splitting and punching produced dust concentrations of only 3.2 million particles per cubic foot on the average. Consequently, no pneumoconiosis cases were seen in that group of workers. In mica grinders, symptoms of pneumoconiosis appeared between the tenth and nineteenth year of employment. The disease symptoms resemble those of silicosis. The symptoms were supported by x-ray diagnosis indicating granulomas and fibrosis of the pleura. The following figure taken from the bulletin dramatically portrays the time-concentration relationship of dusty trades with respect to the development of pneumoconiosis. (Fig. 5) This figure represents the findings in 798 workers including the 57 mica workers exposed to mixed dust and classified according to length of employment as well as the average dust concentration. The graph deals with all pneumoconiosis cases. After five years of employment, the number of workers in each grouping decreases with the increase in years of employment. The percentage represents the chance of finding pneumoconiosis. The 66 percent group consists only of six individuals of which four had pneumoconiosis. Of interest is Appendix II in the study, produced by Dr. John W. Miller. He used some of the minerals encountered in the



RELATION OF AVERAGE DUST CONCENTRATION AND DURATION OF DUST EXPOSURE TO THE PERCENTAGE OF WORKERS FOUND TO HAVE PNEUMOCONIOSIS

Dreessen, W. C., et al., p.50.

Figure 5.

study to conduct an animal experiment with guinea pigs. He used finely ground muscovite mica with a very small amount of quartz and feldspar present. He found that mica produced an "inert reaction." The term "inert" he defines as a condition when the dust remains practically unchanged in the tissue and does not institute a proliferation reaction like the more soluble quartz. The microscopic appearance of the muscovite dust used was described as "plates and fibers."

The field work was conducted between 1937 and 1939. The study was published in 1940. At that time it was standard practice to report airborne dust concentrations in million particles per cubic foot. This dust counting method had quite a few drawbacks as the assessment method for airborne dust concentration. In the 1979 American Conference of Governmental Industrial Hygienists adopted a method to convert million particles per cubic foot to a mass limit of milligrams per cubic meter. A good approximation is 6.37 million particles per cubic foot as being equal to 1 milligram per cubic meter. The converted threshold limit value for a 40 hour workweek is, therefore, 3 milligrams per cubic meter for respirable size particles and 6 milligrams per cubic meter for total airborne dust.[9] Respirable dust particles are those with aerodynamic diameter of less than five microns. It is interesting to note that the British threshold limit value for mica is one milligram per cubic meter for respirable size and ten milligrams per cubic meter for total airborne dust.

The late 1940's and early 1950's produced a series of large scale employee surveys in American occupational medical literature. Vestal and others in 1943, reported a high incidence of tuberculosis upon clinical and x-ray examinations of 1,021 men applying for work in the mica industries in North Carolina. Even though there was no associated field investigation, Vestal's conclusions indicate that dust and tuberculosis pathology among the workers previously exposed to "pure mica" is more pronounced than among those exposed to other minerals.[10] This conclusion was later questioned because quartz was present in all of the other minerals.[11]

Dr. Adelaide Ross Smith, working with data gathered by the New York State Department of Labor, published a paper in 1952 on calcifications of the pleura resulting from exposure to certain dusts.[12] The paper which is based largely on chest x-ray survey data conducted by the Division of Industrial Hygiene of New York State Department of Labor, reports the following:

"A group of 302 men exposed to mica dust were employed by a concern engaged in making mica insulators of various types. Mica is a complex silicate of potassium, aluminum, magnesium, calcium and fluorine. A number of operations in the plant were dusty, including the sawing, sanding and drumming of insulators. None of the mica workers in this study showed pneumoconiosis though Dreessen and others have found that mica dust is capable of causing this condition if present in sufficient intensity." Unfortunately, this study does not mention any concentrations to which these workers were exposed. The length of employment is mentioned in two clinical cases described. The report does state that lung calcifications were found in five of the 302 workers reviewed. As these were x-ray findings they do not deal with the origin of calcifications.

Jones' hypothesis of 1933 found an echo in 1947. King and others associated with the British Postgraduate Medical School in London, investigated South Wales sericite and illite due to their association with coal mining. Two different sericite samples from different geographic locations were used in an insufflation experiment with rats. The dust samples were split and half of the dust aliquot was treated with hydrochloric acid and then neutralized before administration to test animals. The experiment ran for two months. Acid treated dust released silicilic acid in the lung with considerable ease, producing fibrous nodules in the test animals. The untreated half of the dust produced only fibrous phagocytosis.[13] Please remember that sericite and shale both contain substantial amounts of free silica.

In 1953 and 1954 two articles appeared in literature describing medical examinations of 329 mica miners from Bihar, India and of dust exposures to 61 mica factory workers in the same region; they processed crude mica.[14] The exposure data on mica miners resembles those described by Dreessen in his North Carolina survey. Mica processing and grinding exposures range from 44 to 300 million particles per cubic foot with an average of 135 million particles per cubic foot. The mica was muscovite, which contained less than 1% of free silica. The environmental, as well as the previous work history, was not given. The point was made that very few of the examined workers had been working with mica for more than 5 years. Granulomas, found in the chest x-rays, were not beyond "ground glass II" reading. Nodular or conglomerate fibrosis was not observed.[15]

The 1960's produced more research in physiology and pathology of the lung in the dusty trades. In 1966, two Rumanians - Tripsa and Rotaru - published an article entitled "Experimental Studies in Pneumoconiosis Induced by Mica Dust."[16] They introduced intratracheally into rats a one-time dose of 50 milligrams of sized mica suspended in a saline solution. They concluded that small mica particles below 6 microns in size travel to the hiliary lymph nodes, whereas the 20 to 25 micron particles remain lodged and display a higher pathogenicity. They speculate that this particular observation may depend on mechanical damage during the injection and irritative action, and therefore it might not be correct.

In 1962, Vorwald and others published a report on an autopsy case of a rubber worker who during 33 years of employment was allegedly exposed for 21 years to "soapstone" dusting powder. The autopsy lung specimen contained needle like crystals. The presence of both soapstone (fibrous talc) and biotite was determined by x-ray diffraction. The diagnosis was "fibrogenic pneumoconiosis induced by mica."[17] The point in this case is perhaps the lack of recognition for total combined impact, not only the mica and the talc but all the other air contaminants which would be found in a rubber goods factory in the 1940's and 1950's.

In 1968, Lewis J. Cralley and others published an article entitled "Source and Identification of Respirable Fibers."[18] In it they discuss the autopsy survey statistics of several authors indicating presence of fibrous bodies in the lungs of city dwellers. Four to six percent of those occupationally non-separated autopsy cases described in seven studies showed "numerous fibrous bodies." Cralley and others concluded that this finding was not a chance event.

The implication was that fibers are present in the lungs of city dwellers in quantity.

They further included a table of minerals with "fibrous-like structure" taken from the text by Deer, Howie and Zussman. This test was published in 1966. In it, sheet silicates, specifically the mica group (muscovite) are classified as having fibrous-like structure. With regard to the mica group, this may be an imprecise statement. Structurally, true fibers are not found in micas, except as impurities. As you will see later, the fine particulates associated with mica are bladed, play or lamellar in appearance.[19]

In 1968, Mihajlov and Berova (in Bulgaria) published a paper which describes the study of occupationally caused lesions associated with the production of asbestos and mica.[20] As only an abstract was available at the time of writing this paper, the reported role of mica in occupational dermatoses could not be determined.

In 1969, Landwehr and Bruckmann in Germany in an article on mineral composition of pulmonary and suspended dusts, observe that secondary minerals appear to inhibit or promote the effect of quartz in the lungs. They specifically mention iron hydroxide as an inhibitor and anthracite coal as a promoter.[21] This phenomenon was also observed by some Russian scientists who conducted an experiment in 1975 with calcium hydroxide coated silica particles.[22] The same inhibitory effect was also reported by G. Reichel and others in 1975 describing the findings of relative absence of silicosis in a large German iron mine work population.[23] These observations, if confirmed to be effective also with mica dust, may diminish the risk of use of mica when mixed in a chemically basic matrix. A comparison experiment between the effect of pure silica dust, pure muscovite dust and a mixture was performed by Starkov et al at the Medical Institute in Irkutsk, USSR during 1970.[24] In a 12 month experiment using rats, the researchers measured the increase in collagen in rat lungs after a one-time administration of dust intratracheally. The control animals, exposed only to the intratracheal administration of the saline solution, increased the lung collagen content by 2.5 percent over a period of 1 year. This probably represents normal aging. The rats exposed to muscovite increased the collagen content of the lungs by 4.4 percent, the mixed silica and mica dust caused 5.5 percent increase and the administration of the pure quartz resulted in 9.9 percent of collagen increase in the lung in the same time frame. They also observed that the collagen increase in the lungs progressed more rapidly after 6 months of the dust administration. This coincided with beginning of fibroblastic proliferation in the parenchyma of the lung.

In 1972, J. M. G. Davis in Britain reported on a series of experiments regarding the fibrogenic effect of mineral dust injected in the pleural cavities of mice.[25] One of the 16 materials used was chlorite, a relative of biotite, "with a layered structure which in many ways resembles micas." Mice were administered an interperitonial 10 milligram one-time dose. All materials produced granulomas. Granulomas were produced within 2 weeks progressing to a fibrosis stage and these fibers gradually being replaced by collagen in a period of 6 to 8 months. This progression of events perhaps on a different time scale, is fairly characteristic of the human experience. To put it plainly, inert dust in the interstitial spaces of the lung causes a very low level gathering of cells around the dust particle. In a short time connective tissue is formed around the particle. This tissue eventually hardens and becomes scar tissue. Of course, I'm speaking of the particles which have not been removed by mucous and ciliary action. The vast majority of inhaled particles is removed in that fashion. As a source of information, volume 200 of the Annals of New York Academy of Sciences, published in 1972 is entirely devoted to the lung and associated dust diseases. It is an excellent reference volume.

In 1973, the Industrial Toxicology Center in Lucknow, India, produced at least four papers on body fluid response to mica (muscovite).

One paper describes the repeat of the collagen experiment conducted by Starkov et al. that the observations are histological and microscopic, rather than gravimetric. The process of fibrogenesis, as reported by Davis, is confirmed. The transport of dust particles in the lung lymphatic system is briefly discussed. The authors also claim hemolysis of erythrocytes by muscovite "in vitro."[26] This finding has been challenged.

Polyvinyl pyridine N-oxide was found to inhibit erythrocyte hemolysis "in vitro."[27] The solubility of kaolin, micas and talc in presence or absence of citrate, in buffer solution, defibrinated plasma and in serum is reported.[28] Solubility and concentration of silica and silicates in the lung has apparently a proportional negative influence on the enzymes which function in the lung.[29]

In 1974 Pott, Huth and Fredericks in Germany, conducted a test to determine tumorigenic effect of fibrous dusts on rats. They used the direct interperitoneal injection of dust suspended in saline solution.[30] Of the fifteen materials tested, only biotite and hematite did not produce tumors. The dust "fiber" size was less than five microns. The authors are convinced that dust induced carcinogenesis depends on the shape factor. However, there were many unanswered problems regarding this hypothesis.

Shanker and others reported on another experiment with Indian muscovite in 1975.[31] The experimental animals in this case were guinea pigs. The experimental design was focused on the lymphatic transport and the cytotoxic effect of mica in the lung. The cytotoxic effect was not considered pronounced and the fibrotic lesions consisted of reticulin fibers (connective tissue). The fibrogenic response was considered poor. The experiment was of 1 year duration after the intratracheal injection.

In 1976, in a French study, Berry, Henoc and others reported on the application of electron microscopy and electron micro-defraction in differentiating and detecting minerals found in the lungs of hospital patients.[32] Of the 90 cases reviewed, 50 had a history of pneumoconiosis. In the cases associated with silicoses, muscovite and biotite were also present.

A health hazard evaluation was conducted by NIOSH in 1976 in a mica paper operation.[33] The complaint was nasopharyngeal irritation. The causal relationship between mica and the symptomology present was suggestive but not conclusive.

In 1975-76 the effects of phlogopite and muscovite dust in combination with shellac and glythallic resin were studied in rats by Dianova and others at the Moscow Medical Institute.[34] The study lasted 12 months. One group of rats were intratracheally treated with 50 milligrams of either phlogopite, muscovite, shellac or glythallic resin dust. The other group received the same doses of mica dust except 20 milligrams of resin dust were added to each dose to provide phlogopite/shellac, phlogopite/glythallic resin, muscovite/shellac and muscovite/glythallic resin exposure simulation. When the animals were sacrificed in the pure mica exposure group, internal organs such as liver, heart and spleen showed uniform and nominal changes indicating a low level of irritation. In the lung, granuloma was observed in the early stages in 12 months. Shellac and resin dust caused a more pronounced hepatocytic reaction in the liver and irritative reactions in the lungs.

The second group of animals (the combined materials) tested revealed that the resin compound dust and shellac dust have an inhibiting effect on formation of collagen in the lung as compared to mica exposure alone, even though allergenic or toxic effect on the rest of the body was more pronounced.

A concurrent industrial hygiene and medical study in a micanite plant indicated airborne dust concentrations of the tested materials between 8.5 and 134 milligrams per cubic meter. Of 82 examined workers, 7 cases of pneumoconiosis were found. At the same time 6 cases of chronic bronchitis and 3 cases of lung calcifications were diagnosed. As a result of the animal study, a combined threshold limit value of 2 milligrams per cubic meter for the activity is recommended.

In 1977, Sedov and others from the Irkutsk Medical Institute describe a study of 363 underground mica miners.[35] The miners were exposed to dust concentrations up to 20 milligrams per cubic meter, peaking at 31 milligrams per cubic meter. Airborne free silica content is reported between 2 and 71 percent. Twenty-nine cases of pneumoconiosis and two cases of tuberculosis were found. All affected miners showed bilateral fine grain fibrosis. Some had linear thickening of the pleura. The first x-ray findings came after 13 to 17 years of underground work. The authors conclude that pneumoconiosis develops after a long period of time in the mines, and is characterized by diffuse fibrosis, weak desquamic bronchitis, emphysema and presence of mica particles in the lungs. The authors obviously are describing a mixed exposure situation.

In 1978 two Portugese authors report a case of lung fibrosis complicated by an enlarged liver which, upon autopsy, is found to contain sarcoidal granulomas. Both conditions are attributed to muscovite mica due to 7 years of work history in mica grinding.[36]

Finally in 1979 a fairly extensive article on silicate pneumoconiosis appeared in the American pathological literature. A simple pneumoconiosis with lamellar birefringent crystals is reported by Brambilla et al, observed during the autopsies of animals which died in the San Diego Zoo. In 100 autopsies of 11 mammaliam and 8 bird species, interstitial fibrosis was present in 20 percent of the cases. Seventy percent of the particles analyzed in the autopsy specimens were muscovite mica or illite clay. The mica was also present in atmospheric air samples obtained in the zoo. The authors also report similar mica induced lesions found in humans living in the region of Southwest

USA. It is a well written article touching on the naturally occurring environmental exposures.[37]

Finally, a recently released MSHA informational report (IR#1111) lists 152 "minerals which may occur in fibrous habits or mineral suites which may contain minerals of a fibrous habit."[38] Illite and sericite are included. Muscovite, biotite and phlogopite are not.

To summarize the findings and impressions from the literature search conducted for this paper, I would like to make the following notes:

(a) Mica crystal lattice does not produce fibers even though some deposits and products may contain fibers of other minerals as impurities. Mica produces bladed or platy particles when crushed or milled.

(b) Respirable mica particles trapped in the lung act as inert foreign bodies. Generation of scar tissue results. TLV for mica was set more than 20 years ago. Other than conversion to gravimetric method of sampling, there has been no reason to change it.

(c) Experimentally pure mica dust produces less fibroses and at a slower rate than the mixed dust or quartz particles after an equal time and concentration exposure.

(d) Micas have not been reported to support tuberculosis in the lung.

(e) Micas have not been identified as carcinogenic, clinically or experimentally.

(f) Granuloma and functionally noticeable fibrogenesis due to mica dust in humans is reported after very prolonged exposures to high concentrations of dust. It almost has to be mixed occupational exposure.

(g) Judging from the employee exposures and airborne concentrations reported in the literature and from the medical survey data, the prevention of fibrogenesis attributable to airborne mica dust should be relatively simple.

(h) The word "fibrous" should be used more judiciously. In the context of the lungs, it means protective body reaction, not related to the shape or nature of the offending particle.

(i) The speculation that coating of the mica particles with other material, especially chemically basic substances, inhibits fibrogenesis should be considered for experimentation.

There were a dozen references which were mentioned in literature, but were not available for the preparation of this paper.

Martin Marietta operates a phlogopite mine in Canada with a very large and uniform deposit. As the question of presence or absence of fibers had to be resolved, we decided to perform a sampling experiment. Seventeen trays of exploratory core drillings were arbitrarily removed from storage and 1 to 2 inch sections were taken from each tray. The samples were ground to 40 mesh size. One electron microscope target was made from each ground sample. Six photographs of each sample were produced by resetting the field selection controls at random and refocussing. Seventeen sets of such pictures were produced. None of the pictures showed the presence of fibers. Magnification was held at 2,000 times. From the 17 sets, 3 were selected for presentation today. Ten foot, 152 foot and 342 foot levels were somewhat arbitrarily chosen. The six pictures in each set were reviewed for detail and clarity and one was selected. One centimeter on the photograph equals 5 microns in actual dimension. (See Appendix). Some flakes stand on edge and appear acicular.

We also photographed 12 commercial samples obtained from other mica producers. The fine residue in the sample bags was used to prepare the electron microscope sample. Again, a series of six views at random were obtained. The samples represent mica of the Soviet Union, Europe, India and the United States. The same selection technique as in our own core samples was used for presentation selection. Again we found no fibers. We will grant that the method used is somewhat cursory, however, with certain refinements it can be used as a statistical tool to anticipate presence or absence of fibers in a commercially useful ore body. We will endeavor to show all of the photographs obtained in the survey to interested parties.

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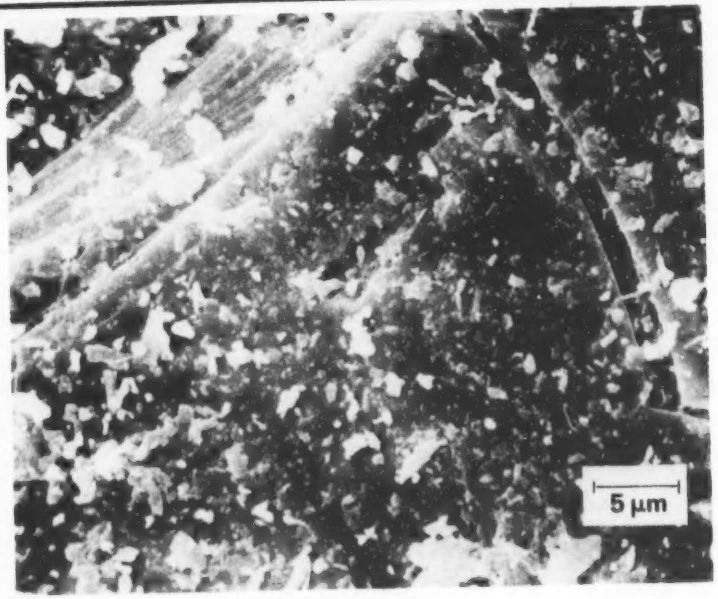
APPENDIX



PHLOGOPITE - CANADIAN - CORE SAMPLE 152 FT. LEVEL

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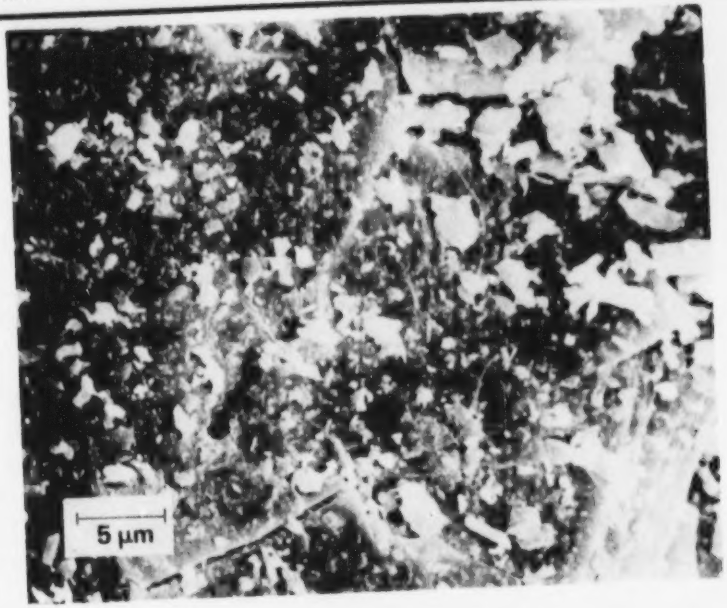

PHLOGOPITE - CANADIAN - CORE SAMPLE 10 FT. LEVEL

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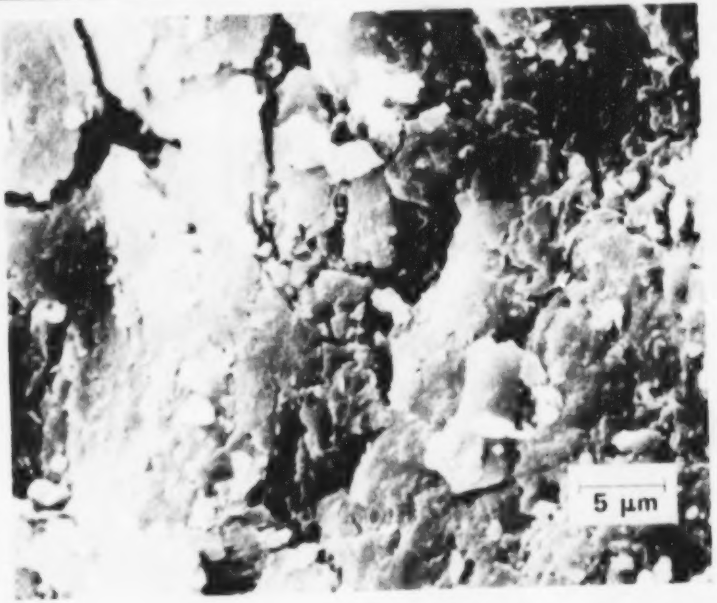

PHLOGOPITE - CANADIAN - CORE SAMPLE 342 FT. LEVEL

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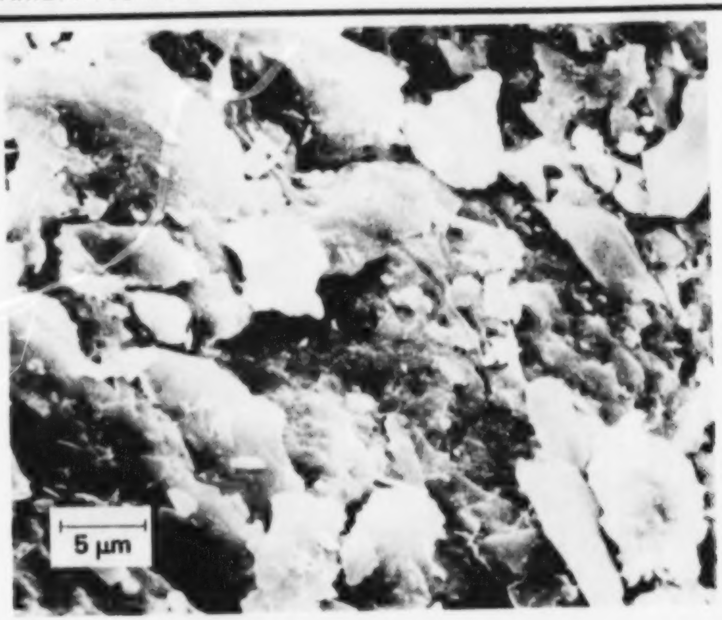

PHLOGOPITE - USSR

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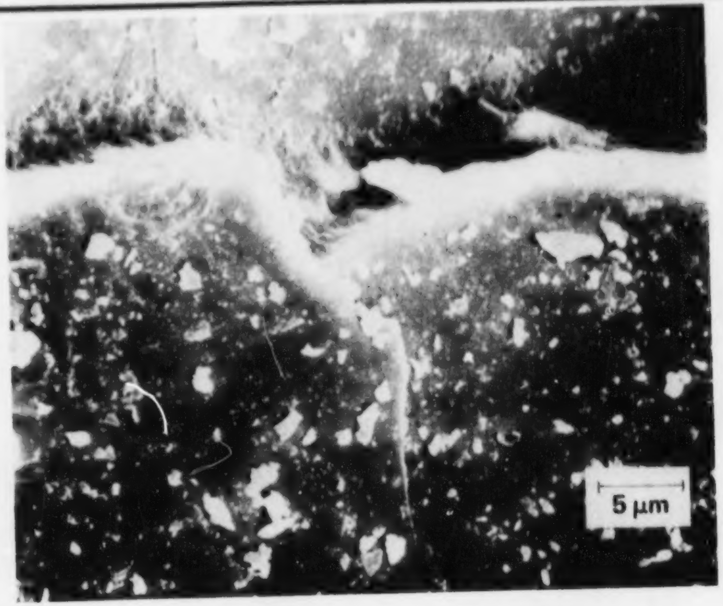

MUSCOVITE - EUROPEAN

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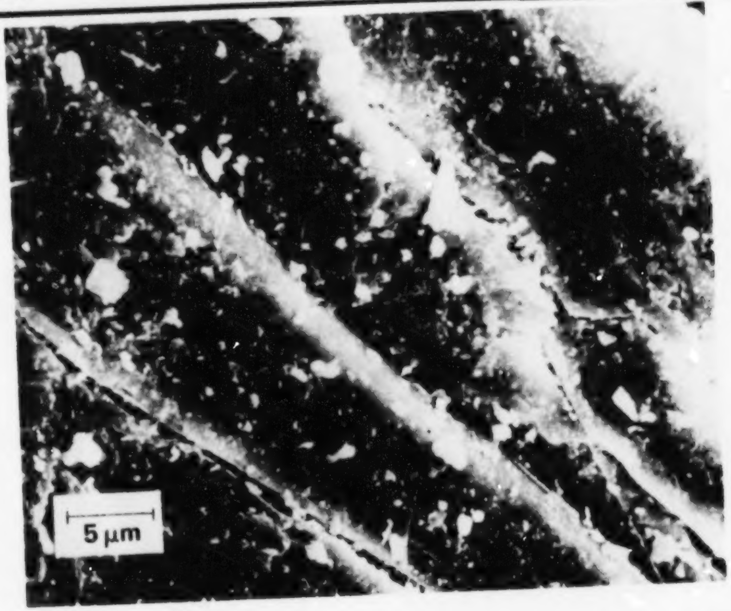

MUSCOVITE - INDIA

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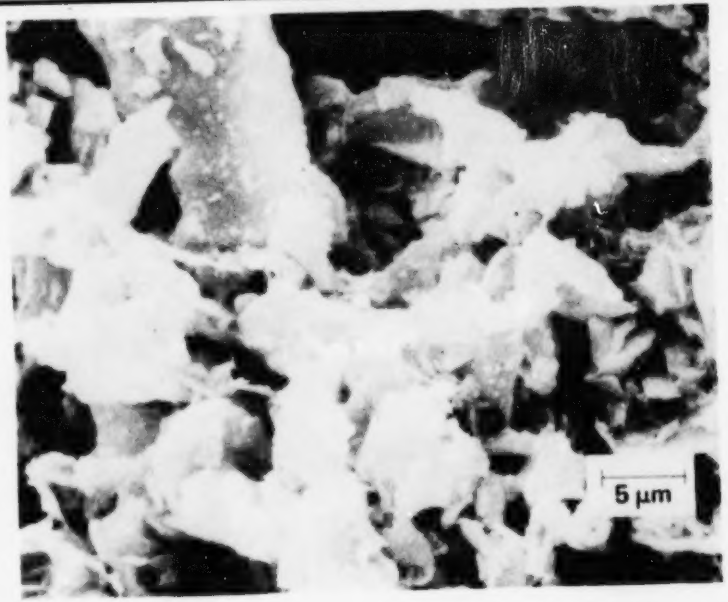

MUSCOVITE - INDIA - MICRONIZED

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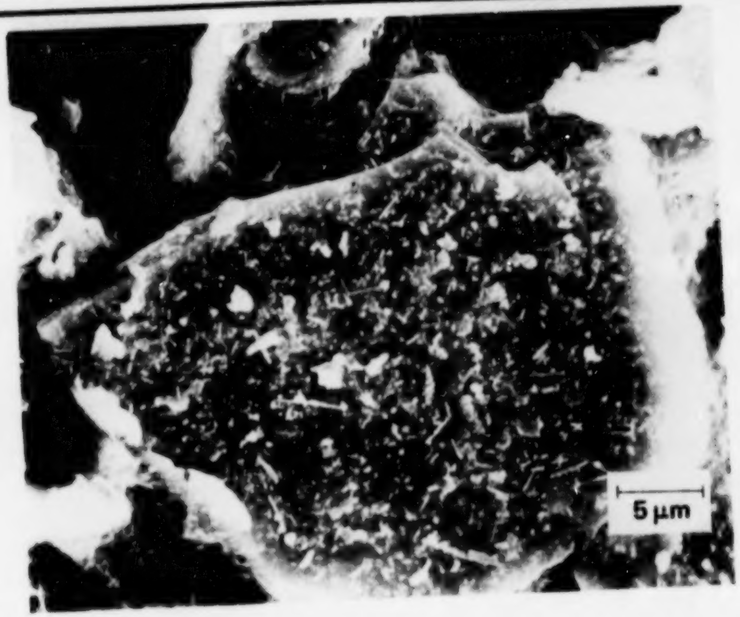

MUSCOVITE - NORTH CAROLINA

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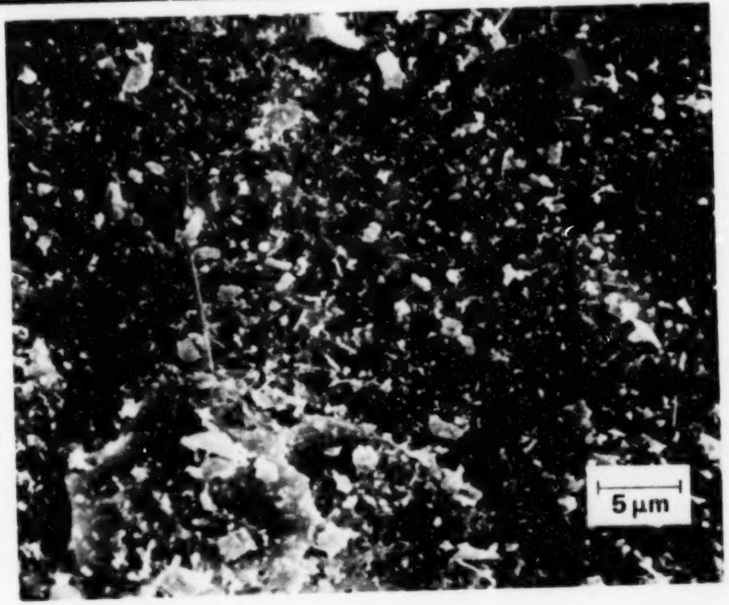

MUSCOVITE - NORTH CAROLINA - FINE GRIND

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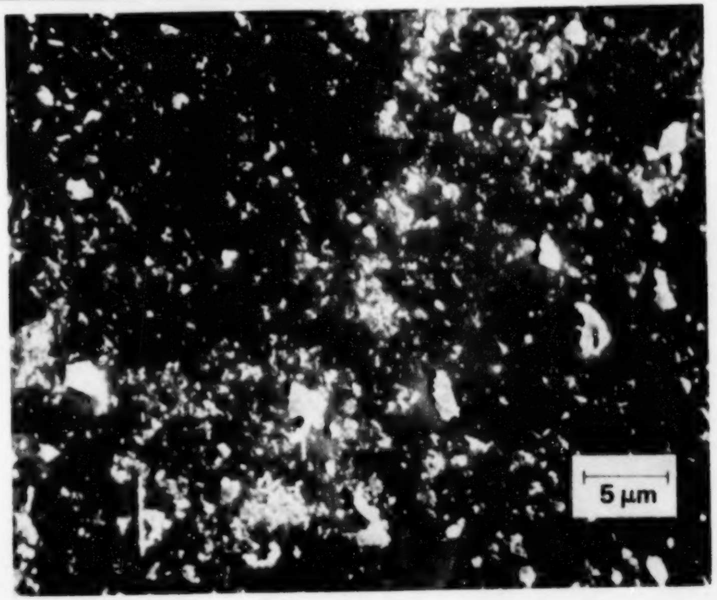

MUSCOVITE - NORTH CAROLINA - COARSE GRIND

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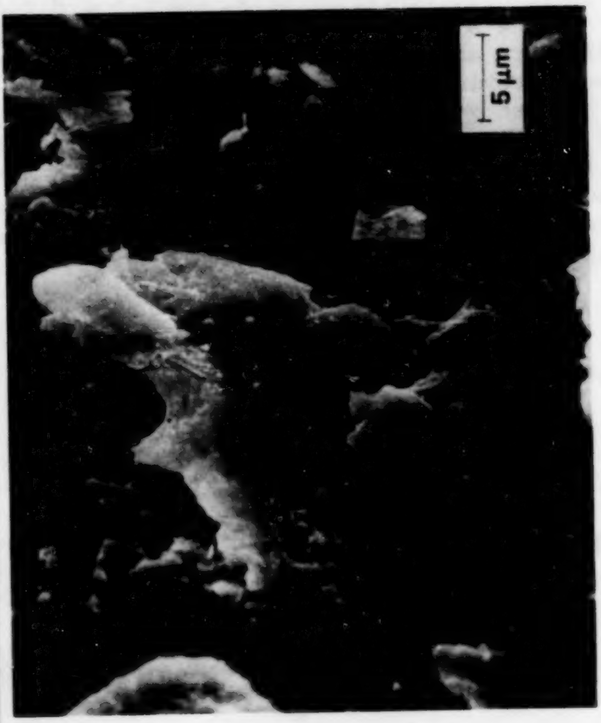

MUSCOVITE - SOUTHERN NORTH CAROLINA

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DISCUSSION ON MICA

QUESTION (Mr. Stumpf): I am from U.S. Mineral Products. I noticed in your chart, from one of the micas, that you reference vermiculite, which I understand at times does have some fibers. You indicate that your Canadian mica contained no fibers. Are fibers associated with some of the other micas and in what part of the United States?

ANSWER (Mr. Lusis): I really cannot answer that truthfully. My personal knowledge of the presence of particulates in mica is restricted to the 156 electronmicroscope slides which I observed.

In reviewing the literature, I did see a couple of pictures, especially in the foreign literature, which would claim to be mica and there would be a few particles in them. But in the cursory survey we did here and from a rough statistical point of view, I am fairly well convinced that in the U.S. markets of the ground micas, you have to go back to the manufacture process. Most of U.S. ground mica is washed before you get it. That is part of the separation process of kaolin; you take kaolin out and then you get some mica from it. So, again, in some European micas you could get fibers; but from the commercial samples we received, I did not see any.

HEALTH EFFECTS OF VERMICULITE

by

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ABSTRACT

Vermiculite is a geologic name given to a group of hydrated laminar minerals which are aluminum-iron magnesium silicates resembling mica in appearance. When subjected to heat it has the unusual property of exfoliating or expanding due to the interlaminar generation of steam. The present study includes an analysis of the physical and chemical characteristics of vermiculite; an industrial hygiene survey of a plant which utilized crude vermiculite in an industrial process; and the results of some preliminary information on a cross-sectional morbidity study of exposed workers.

Depending on source location raw vermiculite may be contaminated with tremolite-actinolite asbestos. Contamination is greatest in vermiculite obtained from Montana and least from vermiculite obtained from South America. Preliminary investigations of workers suggest a high prevalence rate of pleural and possibly parenchymal lung disease. There were nine employees identified with benign pleural effusions, believed to be on an occupational basis. It appears that adverse health effects from vermiculite are the results of contamination with tremolite-actinolite asbestos and not related to vermiculite itself.

This report will review various physical and chemical properties of vermiculite, and present preliminary data on a medical survey of employees using vermiculite as a carrier for fertilizers and herbicides.

CASE REPORT

Dr. John Pryor from Ohio State University first observed what appeared to be an unusual number of pleural effusions in employees of a fertilizer plant using vermiculite as a carrier.[1]

A typical patient was a 40-year old male in a good state of health until five months prior to hospital admission, when he developed an upper respiratory infection, cough, shortness of breath and loss of appetite. He had one flight dyspnea and could walk one block at a slow pace on a level surface.

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*Presented by Dr. James Lockey.

The patient worked for 15 years with a company manufacturing fertilizers and pesticides using vermiculite as a carrier. The majority of his time was spent in an area processing raw vermiculite from an unexpanded to expanded (exfoliated) form. There was no other significant employment history.

The chest X-ray revealed bilateral pleural effusions greater on the left than right, and bilateral lower lobe linear fibrosis. Pulmonary function tests were consistent with restrictive lung disease with no evidence of airway obstruction. Examination of the pleural fluid revealed grossly bloody fluid with a red cell count >200,000. A left-sided decortification procedure was performed in which a 5 mm thickened pleura was removed. Subsequently, a right-sided pleurectomy was performed in which 10-25 mm of thickened pleura was removed. Pathological examination showed chronic inflammation and fibrosis; no asbestos bodies were noted in lung or pleural tissue. No asbestos fibers were found by X-ray diffraction.

There have been nine additional cases of pleural effusions in employees working at this plant. The majority of cases were diagnosed after 1974 with two cases reported between 1969-1971. The mean age of the employees was 46 years, and the mean duration of employment was 15.5 years. The location of the effusion was on the right in seven cases, left in two cases, and bilateral in one case. One employee had evidence of pulmonary fibrosis. The majority of these employees worked in one area of the plant processing raw vermiculite. Seven employees had examination of the pleural fluid. Five were grossly bloody with white counts >1,000. Five of seven were exudative in nature with protein content >2.5 gm. Five employees had pleural biopsies with evidence of inflammation and/or fibrosis.

CHARACTERIZATION AND USES OF VERMICULITE

Vermiculite is the geological name given to the group of hydrated laminar minerals that are aluminum-iron-magnesium silicates. The crystal structure is similar to mica and biotite. The mineral can expand or exfoliate up to 20 times its original size. This property is dependent on the generation of steam from the intrinsic water content with the application of heat between 300-1500°F. As it expands, it becomes curved or "worm-like," hence the name vermiculite from vermicular meaning "to produce worms."[2,3]

Vermiculite is a secondary mineral derived from trioctahedral micas, phlogopite, or biotite, by geochemical alteration. The geologic deposits are usually associated with mica.[4] The chemical composition of vermiculite is shown in Table I. The SiO_2 content is 37 percent and the aluminum content is 14 percent. The high aluminum content is in contrast to the much lower content in asbestos. Before exfoliation, the water content is 20 percent.

A potential health problem with vermiculite is the contamination of the raw ore with asbestos. Recent studies utilizing X-ray diffraction, dispersion staining with polarized light microscopy, scanning electron microscopy with energy dispersion X-ray analysis, and transmission electron microscopy with selected area electron diffraction revealed varying concentrations of tremolite-actinolite in North American ores. Tremolite-actinolite belongs to the calcium amphibole family and they are very similar in crystal structure and elemental composition.[5,6]

The previously identified chrysotile-like fiber in South African ore is believed to be rolled-up scrolls of vermiculite and not asbestos fibers. These scrolls form at the cracks in vermiculite plates. They are of tubular morphology and tend to form bundles similar to chrysotile. The transition to scroll configuration includes the reduction of magnesium and aluminum concentrations relative to silicon.[7]

Vermiculite has multiple uses including insulation, waste filtration, soil additive, and as packaging material. As an aggregate in plaster and concrete, it decreases the weight and adds insulating and fire resistant properties.

In mines vermiculite is used as a sealant for control of spontaneous heating, sealing air crossings, fire-proofing road ways, and for consolidating pack sides. Processed to a finer grade, it is used as a sound-deadening material, in flame resistant paints, handboards, plasters, and as fillers in plastics, rubber, roofing and flooring material. In agriculture, it is used as a carrier for herbicides, insecticides, fungicides, fertilizers, seeds, and as a bulking agent in animal feed.

INDUSTRIAL HYGIENE DATA OF PLANT

Industrial hygiene measurements were initiated in 1972. The first measurements for total dust and fiber content according to OSHA criteria for asbestos fibers were elevated within the expander area. These initial high levels probably represented the general condition of the working environment within the expander area since the plant was constructed. With the institution of procedure changes and environmental controls, the company has been in compliance with present and pending OSHA regulation for total dust and asbestos fibers.

PILOT MEDICAL SURVEY

Because of the apparent high number of pleural effusions in employees within the vermiculite expander area of the plant, a pilot medical survey was initiated in 1979. Chest films and pulmonary function tests of 125 employees were reviewed. There appeared to be an increase prevalence of pulmonary abnormalities in employees processing vermiculite to an expanded form. Confirmation of this preliminary data awaits analysis of a recently completed cross-sectional epidemiological study of all employees of this plant.

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TABLE I. CHEMICAL ANALYSIS OF UNEXFOLIATED VERMICULITE

	Type or Source of Material			
	Theoretical vermiculite	Libby Mont.	Palabora, South Africa	West Chester Pa. (jefferisite)
SiO_2	36.71	41.0	39.37	34.30
TiO_2	------	------	1.25	------
Al_2O_3	14.15	18.0	12.08	16.58
Fe_2O_3	4.43	7.0	5.45	7.41
FeO	------	------	1.17	1.13
MnO	------	------	.30	------
MgO	24.62	21.0	23.37	20.41
CaO	------	1.0	1.46	------
Na_2O	------	1.0	.80	------
K_2O	------	1.0	2.46	------
H_2O at 150°C	20.09	11.0	11.20	21.14

From Otis, L.M. (3)

DISCUSSION ON VERMICULITE

QUESTION (Mr. Carton): I am with the EPA. I would suggest if you are using controls from the plant, you would not get a definitive study since the majority of the employees would be exposed to some of the material in the air surrounding the plant.

The second point, please elaborate on the vermiculite fiber that was felt initially to be chrysotile.

ANSWER (Dr. Lockey): In answer to your second comment, the initial analyses of vermiculite (prior to 1977) revealed possible contamination with chrysotile asbestos. Later analysis confirmed the presence of tremolite-actinolite in Montana Ore.

Analysis of South African ore by scanning electron microscopy with energy dispersion X-ray analysis and transmission electron microscopy with selected area electron diffraction revealed fiber morphology believed to represent vermiculite scrolls.

QUESTION (Mr. Carton): Was this fibrous? And if it was, have you accounted for it by measuring it in your industrial hygiene survey? You may be missing a fibrous compound if all you are looking for is just the asbestos.

ANSWER (Dr. Lockey): The vermiculite scrolls are considered fibrous by OSHA criteria. A complete qualitative analysis has not yet been performed on the nonasbestos fibers obtained during industrial hygiene sampling. This analysis will be completed in the near future.

QUESTION (Mr. Carton): I think it is unusual to be getting abnormal results in such a short amount of time with asbestos exposure. Should you not be thinking of something else other than asbestos?

ANSWER (Dr. Lockey): The time interval for the development of pleural changes including pleural effusions after asbestos exposure is consistent with the exposure history of the plant under study. These benign effusions often occur within 10 years of exposure. Toxicity studies in animals with asbestos-free vermiculite and asbestos-contaminated vermiculite need to be performed to determine their relative toxicity.

REMARK (Mr. Carton): I was concerned about the fact that you are using people in the plant as controls and not an outside group.

REMARK (Dr. Lockey): We plan to use, as our control population, employees from a physically separate plant with no history of exposure to vermiculite.

REMARK (Dr. Wiley): I am from the University of Maryland. I think Eric Chatfield has published some photographs of the curled edge of vermiculite that indicates that they look very similar to chrysotile.

I would like to make another comment. The word "tremolite" and the word "asbestos" are not synonymous, nor is the word "actinolite" a synonym for the word "asbestos." I think if you are going to claim certain vermiculite deposits contain asbestos, you need more than the presence of mineral tremolite or actinolite to make a judgment.

REMARK (Dr. Lockey): There is some controversy concerning the classification of tremolite-actinolite. The chemical and crystal composition of tremolite and actinolite are very similar. Present OSHA asbestos regulations include tremolite.

QUESTION (Dr. Ross): I am from the U.S. Geological Survey. What labs did these analyses?

ANSWER (Dr. Lockey): The more recent analyses (after 1977) of the vermiculite ores were done by independent labs under the contract to the company under study and the South African Mining Company. They include the Navy Environmental Health Center in Cincinnati, the Ontario Research Foundation under Dr. Eric Chatfield, and the Walter C. McCrone Associates, in Chicago.

REMARK (Dr. Ross): I would like to make a general comment. A Geological Survey science department in this country that teaches minerology/petrology would have no trouble in making these identifications.

REMARK (Dr. Lockey): A majority of the vermiculite analytical work was performed by independent laboratories prior to our involvement. An independent complete analysis of all commercial sources of vermiculite needs to be undertaken.

REMARK (Dr. Langer): I am from Mt. Sinai. I will have to take issue with the geologist from the United States Geological Survey. If an analyst does not have available the knowledge of the physical character of the mineral as it occurs in geological outcropping (either tensile strength or fiber flexibility), you cannot use the term asbestiform or asbestos for any submicroscopic fiber. Asbestos applies to specific physical conditions of fibers in the natural aggregated state.

If one examined fibrous material by electron microscopy, whether it is by transmission electron microscopy or by scanning electron microscopy, one must examine a population of fibers. One must also determine by selected area electron diffraction the orientation of the fiber being examined. This is considered critical in that asbestiform minerals tend to cleave along the 010 and the 100 planes, whereas rock-forming amphiboles have the more "normal" cleavage, either 210 or 110. When examining mineral fibers, the only one that you can identify with any surety is chrysotile. Here also some structural clarification may be required. Comminuted amphibole fibers requires a statistical study of particle-orientation to determine if you are looking at a true asbestos fiber. If the nature of the material on the gross aggregate level is unknown, the term asbestos cannot be used.

REMARK (Dr. Wiley): I am from the University of Maryland. I would take issue with Dr. Langer. I think you can probably make a pretty good estimate from population of particles based on their width, their length, their shape analysis as to whether they represent a population of true asbestos fibers, or a population of cleavage fragments. Orientation may not be required.

REMARK (Dr. Langer): Dr. Wiley is absolutely correct. When one has a population of the same mineral fiber, one can determine size-distribution characterization, and on the basis of the width distribution, you can determine if you are looking at amosite, crocidolite, or at some of the other asbestos varieties. That is possible only if you are looking at a pure monomineralic material.

If you are looking at an aggregate population, such as the population that you might encounter in a vermiculite deposit, which may contain an extremely fibrous tremolite in one place and blocky tremolite fragments in another place, one must use the more detailed characterization. Dimensional and morphological analysis does not help.

QUESTION (Mr. Teitlebaum): I am from the EPA. I noticed in your data on the length of employment in relationship to workers with pleural effusions, it seemed like the latent period was much more shorter than one normally sees with asbestos. I was wondering what working hypothesis you are using to explain that or to investigate that further.

ANSWER (Dr. Lockey): The interval for the development of benign pleural effusions after asbestos exposure can range from a few months to over 30 years. Our data is consistent with this.

The company under study does incorporate a number of herbicides and pesticides into their product. If we find a significant increase in pleural changes within the study population that is not isolated to the vermiculite-exposed workers, then we will need to look for another etiology.

QUESTION (Dr. Menuite): Have any quantitative analyses been done on the amount of tremolite-actinolite present in the various vermiculite ores?

ANSWER (Dr. Lockey): Quantitative analyses has been done, but the data is not available at this time.

OPENING REMARKS: NATURAL NON-FIBROUS SUBSTITUTES: TALC

by

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of the City University of New York
New York, New York

Good Evening members of the panel, ladies and gentlemen. Tonight we are to address the topic "Is talc a possible non-fibrous asbestos substitute?".

ASBESTOS

The need to substitute for asbestos in a number of products, and a number of workplaces, has become increasingly more important as data become available which delineate the full extent of its health effects. These data are impressive when one considers the excess neoplastic risk associated with fiber inhalation, including those effects produced in synergism with cigarette smoke. Recent information, discussed at the IARC (International Agency for Research on Cancer) in the fall of 1979, suggests that no threshold limit value exists in so far as fiber exposure and increased risk to cancer is concerned. Therefore, in addition to controlling dust in the workplace, one finds it increasingly more important to limit fiber exposures of all kinds, and reduce asbestos' pervasiveness throughout our industrialized society.

SUBSTITUTION

There are a number of important questions which may be asked of all of us before considering a substitute material to take the place of asbestos: will the substitute material perform comparably on a technical basis?; will the substitute material provide greater "safety" as compared with asbestos, for the worker, the consumer and for the environment?; is the substitute material available in relative abundance?; does the economic outlook favor substitution, including both direct and indirect costs to the manufacturer and eventually to the consumer?; where will substitution take place first?

Substitution is clearly indicated, without undue deliberation, if asbestos fiber is incorrectly used to begin with, e.g., chrysotile asbestos in children's papier maches, where a clay is easily substituted. The issue here is clear-cut: the asbestos fiber was present in an "unbound" state, with a great potential for liberation and inhalation; the fiber was present in a material for which substitution could easily be achieved; the substituted material would have equalled or economically benefitted the manufacturer; the substitute clearly produced a safe product.

TALC

One of the materials currently considered as a substitute for asbestos is "talc". To properly gauge how this material may be used as a substitute it is important to define the nature of talc; determine if its biological potential is clearly known, and provide a sound comparative base with asbestos.

THE NATURE OF TALC

The geological occurrence of talc has recently been detailed by Rohl et al. (1976), 257-258. In that paper, the following was described:

> "Talc rocks (including those commercially worked) are formed by several complex geological processes reacting upon many possible, chemically diverse preexisting rock types. Hydrothermal alteration of magnesia and silica-rich ultramafic rocks, under a range of low-to-moderate temperatures and pressures, may produce talc. Thermal metamorphism of silica-rich dolomite ($CaMg(CO_3)_2$ will produce talc as well. These processes, however, also commonly result in the formation of a number of other coexisting mineral phases, predominantly hydrous magnesium silicates. Some of these, for example, anthophyllite, tremolite, and serpentine minerals (including chrysotile), occur as microscopic intergrowths with talc, as macroscopic nodules, or even as discrete zones within or adjacent to talc. Talc rock is therefore generally not monomineralllic but is often a mixture of minerals that may vary widely with respect to kind and quantity. Phlogopite, a magnesium mica, and chlorite, a group of minerals related to micas, are also commonly associated with talc. Some of these associated mineral phases (may be) asbestiform amphiboles and chrysotile". "Conversely, talc has been described as a common accessory mineral in commercial asbestos deposits (Hurlbut and Williams, 1935). Talc deposits may be zoned, with different mineral assemblages physically changing in occurrence and proportions over extremely variable distances, ranging from centimeters to tens of meters. Mineral phases in such deposits may include talc plates and fibers, tremolite and anthophyllite fibers, intergrowths of amphibole and talc, serpentine minerals (which may include chrysotile), and free silica (quartz) (Ross et al., 1968). The fiber intergrowth is often such that even extensive beneficiation may not yield a pure product. Thus, where fine-grained intergrowths of talc and tremolite occur, the processed product will likely contain residual tremolite".
>
> "It is generally recognized that various commercial grades of talc are marketed in the United States. Hildick-Smith (1976) has stated that a talc suitable for pharmaceutical purposes, used in cosmetic and toiletry products, contains at least 90% talc mineral and no detectable asbestos.

> Such stated compositional restrictions are not placed on industrial grade talcs. One study demonstrated that a number of industrial talcs contained substantial quantities of tremolite, up to 87% by weight of the sample (Schulz and Williams, 1942)".

It is of special importance to note that contaminant amphibole minerals may be true asbestiform (asbestos) varieties, may comminute as acicular cleavage fragments or may form more equant (blocky) cleavage fragments. Morphology may be critical in estimating biological potential. The general chemistry of talc, its structure and crystal habit, the mineral nature of talc intergrowths and other information are provided in Rohl et al., 1976. The above data indicate that talc deposits may consist of intimate admixtures of the mineral talc (occurring as both plate and fiber) quartz, amphibole minerals of different varieties and habits (including true asbestiform varieties) and serpentine minerals (including chrysotile). The important question then is, "if talc is considered as a substitute, which talc do we mean?"

HEALTH EFFECTS

There are a number of health effects which have been observed associated with occupational exposure to talc. These effects have been described in detail in Rohl et al., 1976:

> "A fine, diffuse, bilateral, progressive fibrosis was observed among miners and millers of tremolite talc in Georgia (Dreessen, 1933; Dreessen and Dalla Valle, 1935). Siegal et al, (1943) studied a population of workers mining and milling tremolite and anthophyllite-bearing talc deposits in New York State. In addition to the bilateral fibrosis, pleural plaques, similar to those encountered in asbestos workers, were observed. Review of postmortem material in this study indicated that asbestos bodies were present in lung tissue. These findings were also reported in cases of severe pneumoconiosis in tremolite millers by Daymon (1946), and by Porro and Levine (1946). Millman (1947) reported that exposure to cosmetic-grade talc produced nodular fibrosis in workers. No quartz was detected in the dust. The author concluded that talc itself was capable of producing scarring. The observation was supported in studies by Reichman (1944) and by Wyers (1949) and in a study of talc miners and millers in Italy where exposure to pure talc produced a 10% incidence of pneumoconiosis in workers (Parmeggiani, 1948). Excess deaths attributed to pneumoconiosis have been reported among workers in northern Italy mining talc considered to be free of asbestiform fibers (Rubino et al., 1976).
>
> Some investigators have held that fibrous talcs (not differentiated as talc or asbestos fiber) are biologically more hazardous than platy talcs. For example, in a review of the literature by Porro, et al. (1942), Gloyne and Gardner are referred to as considering that the clinical, radiological, and pathological disease states of asbestosis and talcosis are very similar. There are several reports of the occurrence of asbestos bodies in the lung tissue of workers exposed to talc (Daymon, 1946; Hobbs, 1950; Kleinfeld et al., 1973; McLaughlin et al., 1949; Porro et al., 1942).

> Several studies suggest that fibrous talcs are more dangerous as a result of the included asbestos fiber. For example, McLaughlin et al (1949) compared fibers in talc with the proportion of fibers recovered from the lung tissue of an exposed worker. A larger concentration of fibers was found in the tissues as compared with the raw talc. Talc pneumoconiosis was reaffirmed by Kleinfeld and Messite (1960) in their study of the New York State talc workers.
>
> In a study by Kleinfled et al. (1967) it was demonstrated that talc pneumoconiosis accounted for almost 30% of excess deaths among the talc miners and millers. Most of these were due to the complication of pneumoconiosis, cor pulmonale. However, 21% of the 91 deaths recorded were due to malignant tumors: lung carcinoma, pleural fibrosarcoma, and stomach, colon, and pancreatic cancers. A peritoneal mesothelioma was reported as well. In addition to these tumors, retroperitoneal sarcoma, hepatoma, and leukemia were also found. Statistical evaluation of these data indicated that a 3- to 4-fold excess of cancers existed in this group, as compared to a matched control population.
>
> The biological activity of both tremolite and anthophyllite fibers has been known for some time, and both have been cited as asbestos minerals by Merewether (1930) and Noro (1946). Asbestos disease among workers (and others exposed to anthophyllite and tremolite) has been reported (Burilkov and Badajov, 1970; Kiviluoto, 1960; Meurman, 1968; Meurman et al. 1974, Scherpers, 1965; Wegelius, 1947; Weiss and Boettner, 1967). Recent experimental data also indicate that tremolite fibers are biologically active (Graham and Graham, 1967). Some investigators have suggested that inorganic fiber fibrogenicity and carcinogenicity is limited only by its ability to reach the alveolar space (Holt et al., 1965; Pott and Friedrichs, 1972; Pott et al., 1974; Robock and Klosterkotter, 1976; Stanton and Wrench, 1972).
>
> Wagner et al. (1975) reported lung scarring in Wistar rats with pure talc, exposed by inhalation. The severity and extent of the lung scarring was comparable to that produced by chrysotile asbestos under identical experimental conditions. In addition to lung scarring, ingestion of talc was reported to be associated with leiomyosarcoma of the stomach as well as one adenoma and several sarcomas of the uterus. However, the exposure levels were high and the numbers of observed tumors small, so that statistical validation of the carcinogenic potential of pure talc and its relevance to human exposures were not achieved.
>
> There are also extensive data concerning hazards associated with exposure to silica or trace metals, particularly nickel and chromium (National Research Council, 1975). Analytical data are presented here that suggest possible disease potential and the need for investigation in these areas."

It is obvious that the biological effects are in part related to the nature of the talc deposits, i.e., the nature of the materials to which the workers are exposed.

WHICH TALC?

It is now recognized that a variety of mineral deposits yield an industrial mineral substance called "talc". It is equally obvious that disease patterns vary from geological locality to geological locality which reflects, in part, the mineralogical nature of the deposit. The question may then be asked, if talc is to be considered as a non-fibrous substitute for asbestos, which talc is safe?; are there any talcs which are safe?; are data available to suggest which of these talcs may safely be used as a non-fibrous substitute?

This evening we will hear a report by Drs. Gamble and Griefe which contains information on an industry-wide cross-sectional epidemiologic and industrial hygiene survey of talc workers. This study includes the "pure talc" of Montana (of Yellowstone and Beaverhead Mines), and "contaminated" Texas talc (of Palestine and Van Horn), and the North Carolina talc (Murphy Mine) which consists of a mixture of talc plates and talc fiber. These are the data which are urgently needed to guide the various agencies in their search for safe asbestos substitutes.

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CROSS-SECTIONAL EPIDEMIOLOGIC AND INDUSTRIAL HYGIENE SURVEY OF TALC WORKERS MINING ORE FROM MONTANA, TEXAS, AND NORTH CAROLINA

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ABSTRACT

Two hundred and ninety-nine miners and millers exposed to talc from Montana, Texas, and North Carolina were examined in a cross-sectional study of respiratory symptoms, lung function, and chest X-rays. This population comprises the bulk of talc workers outside of New York and Vermont. Work histories were taken from personnel records. Personal respirable dust samples were collected for all jobs and used in the estimate of exposure for each job. Cumulative exposure was calculated by adding together the results of multiplying the estimated exposure for each job times the length of time worked in that job. The average time worked was 7, 6, and 10 years and average exposure (cumulative exposure divided by the total time worked) was 1.2, 2.6 and 0.3 mg/m^3 in Montana, Texas, and North Carolina respectively. Free silica content of bulk samples was low (below the limit of detection in Montana, 1.5 percent in North Carolina, and 2.2 percent in Texas). No fibers were observed under the light microscope. Under the transmission electron microscope, tremolite and antigorite fibers (0.5 - 3 μm diameter and 4 - 30 μm length) were observed in the Texas talc, acicular particles (aspect ratios 5-10 to 1 and some diameters less than 0 - 1 μm) in North Carolina talc, and no fibers in the Montana talc. There were no differences among the regions by age, smoking and exposure groups in the prevalence of cough (19 percent), phlegm (23 percent), dyspnea (5 percent), and bilateral pleural thickening (5 percent). None of the symptoms showed any consistent association with years worked or cumulative exposure. Comparisons of the prevalence of symptoms and pleural thickening were made with blue collar workers, potash miners, aboveground and underground coal workers, and New York talc workers after indirect adjustments for age and smoking. The

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*Presented by John Gamble and Alice Greife.

prevalence of cough was not different than potash, blue collar, and aboveground coal workers, and less than underground coal and New York talc workers. The prevalence of phlegm was no different than blue collar workers, and was less than potash, coal, and New York talc workers. There was no difference in the prevalence of dyspnea between the study populations and potash, blue collar, New York talc, and was less than the prevalence of coal workers. There were two cases (less than 1 percent) of grade 1 small rounded opacities. The prevalence of bilateral pleural thickening among workers 40 years or older was 7 percent, 16 percent, and 14 percent in Montana, Texas, and North Carolina, and 0 percent, 0 percent, and 10 percent in those less than 40. No nonsmoker had bilateral pleural thickening and there was a slight tendency for the prevalence to increase with exposure. Workers with bilateral pleural thickening had lung function 10 to 20 percent below workers with no pleural thickening. They had also worked twice as long (13 years) and an average of 13 years between beginning exposure to talc and the time of the X-ray. The prevalence of bilateral pleural thickening was elevated in all talc workers compared to all nontalc workers. Reduced lung function showed no association with exposure. After adjustments for age, height, and smoking, FEV_1 and FVC was no different than potash miners and blue collar workers and was 2 to 5 percent less than coal workers. Flow rates at low lung volumes were 4 to 19 percent less than all of the comparison populations.

Although the amount of time worked by the study population was short, there were no increases in symptoms or pneumoconiosis nor biologically significant reductions in lung function. Bilateral pleural thickening was significantly increased. The prognostic significance of the pleural thickening is unknown.

MEDICAL PORTION

INTRODUCTION

Talc is a mineral with a wide variety of uses in paint, paper, ceramics, cosmetics, plastics, roofing products, textile material, rubber, lubricants, corrosion proofing composition, fire extinguishing powders, cereal polishing, water filtration, insecticides, to name a few. Pure talc is a hydrated magnesium silicate, but the talc found in nature has quite a variable chemical and mineralogical composition. The mineral contaminant in talc of most concern is asbestos. The hazard from exposure to "pure" talc free of asbestos contamination is not well documented. The purpose of this study was to ascertain the effects on the respiratory system (symptoms, lung function, radiographic) of exposure to talc dust from the three major U.S. ore deposits that had not been studied.

Talc workers in seven mines and eight mills in Montana, Texas, and North Carolina were studied in this cross-sectional study. The mines in Montana and Texas were typical open pit operations, while the underground mine in North Carolina employed square set timbers and stopes. In each mine examined, typical mucking techniques were employed. ANFO (ammonium nitrate and fuel oil) was the most common type of explosive used.

Following extraction of the ore, the talc is hand sorted to remove extraneous material as in Montana, or goes directly from the mine to the primary crusher. Froth flotation and heavy metal separation techniques were not used in any facility examined. Following initial crushing the talc is calcined, as in the case of ceramic grade talcs, before it was ground using dry grinding methods into the final product. Once the talc was ground to the appropriate mesh size, it might be sterilized as in the case of pharmaceutical grade talc, and then shipped in bags or bulk. The commercial uses of talc in the deposits studied are as follows. Montana talc is used in cosmetics, paints, paper, ceramics, and steatite. Texas talc is used in ceramic tile and insecticides. North Carolina talc is used in cosmetics, crayons, paint, rubber, pharmaceuticals, and steatite.

The specific questions being addressed in this paper are:

- What is the prevalence of symptoms and abnormal radiographic findings by exposure categories within each region? What is the association of exposure with reduced lung function?
- After adjustment for confounding variables, how does the study population compare with other mining and nonmining populations in the prevalence of symptoms, abnormal radiographic findings, and mean lung function?

METHODS

The study population consisted of workers mining and milling talc from three regions of the United States: Montana, Texas, and North Carolina. There was over 90 percent participation. Although several different companies may be involved, the results for each region are combined, as the characteristics of the talc in each region are similar. As there were few regional differences in symptom prevalence and lung function, analysis of combined regions is also presented.

The industrial hygiene portion of the study took place in every facility in which morbidity data was collected and is discussed by Alice Greife.

All workers were administered a British Medical Research Council respiratory questionnaire by trained interviewers. Non-talc work history was obtained in the interview; work experience at the talc facility was obtained from company records. Standard posteroanterior chest radiograms were read by three "B" readers using the ILO U/C 1971 scheme. The films were read independently without knowledge of age, occupation, or smoking history. The median of the three readings was used for analysis. Flow volume curves from a minimum of 5 forced expiratory maneuvers were obtained and recorded on magnetic tape using an Ohio 800* rolling seal spirometer. Values from the maximum envelope were used for analysis. Before and after shift spirometry was administered to workers on the day shift, and personal environmental samples were also collected on these workers. The results of the personal environmental sampling were used to estimate average talc dust exposure for each job. This estimate was then used to calculate cumulative talc dust exposure by multiplying job exposure x time, and adding the results of each multiplication; the units are mg/m^3 x years. The association of lung function and exposure (cumulative exposure and years worked) was analyzed by multiple regression. Exposure variables were defined in several ways. Years worked in the talc industry was divided into <5 years, 5 to 9, and ≥10 years worked categories for analysis of symptoms and pleural thickening. For analysis of symptoms and pleural thickening cumulative exposure was divided into low (<2 mg/m^3 x years), medium (2 to 6 mg/m^3 x years), and high (>6 mg/m^3 x years) exposure groups. These categories were chosen to obtain nearly equal numbers for each group. Differences by region and department (classified according to whether the majority of work was done in the mine, mill, crayon plant, or other) were also analyzed.

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*Disclaimer

The prevalence of selected symptoms and pleural thickening was compared to several mining and nonmining populations after indirect adjustment for smoking and using the age distribution of all populations. Pulmonary function prediction equations were calculated for each smoking category of these comparison populations. The observed lung function of each worker from the study population was compared to the predicted lung function of the appropriate smoking category of the comparison population. The individual observed to predicted ratios from all smoking categories and regions were added together and multiplied by 100 to give percent predicted lung function. Female prediction equations were available for only the blue collar comparison populations. Percent predicted lung function comparisons with the mining population are therefore for males only.

Demographic Characteristics

Table 1 summarizes the characteristics of the three regions. The North Carolina population was slightly older, had worked slightly longer, and had a higher proportion of smokers than the other two regions. Texas had the highest average and cumulative exposure of all the regions, and the smokers smoked fewer cigarettes per day.

Only 11 percent of the workers in Montana and Texas had worked 10 years or more compared to 38 percent in North Carolina. Most of the study population in Montana and Texas had worked less than 5 years (66 percent and 73 percent respectively). About 20 percent in all regions had worked from 5 to 9 years. The correlation of age by years worked, age by cumulative exposure, and years worked by cumulative exposure respectively was 0.63, 0.41, and 0.48 in Montana, 0.36, 0.12, and 0.12 in Texas, and 0.51, 0.33, and 0.44 in North Carolina.

There was one case each in Texas and Montana of Grade 1 small rounded opacities and no cases of pleural calcification. There were no other radiographic interpretations of pneumoconiosis. Cytology on sputums collected from workers 35 years of age or older revealed no cytology suggestive of malignancy.

TABLE 1. DEMOGRAPHIC CHARACTERISTICS OF THE TALC WORKER POPULATIONS BY REGION

		Montana		Texas		North Carolina	
n		177		71		51	
Age	(S.D.)	34.9	(11.5)	38.0	(13.7)	43.1	(12.6)
Height (cm)	(S.D.)	175.5	(8.8)	173.0	(6.9)	172.5	(8.3)
Years worked	(S.D.)	6.6	(6.3)	5.5	(5.7)	10.1	(8.6)
Cumulative exposure (mg/m^3-years)	(S.D.)	5.9	(7.6)	11.3	(45.1)	3.0	(4.8)
Average exposure (mg/m^3)	(S.D.)	1.21	(0.94)	2.64	(7.12)	0.28	(0.33)
Nonsmokers	(%)	33		20		21	
Ex-smokers	(%)	21		27		17	
Pack years	(S.D.)	15.7	(17.9)	13.3	(20.7)	18.2	(16.5)
Cigarettes/day	(S.D.)	23	(15)	12	(14)	21.4	(15.7)
Smokers	(%)	45		54		62	
Pack years	(S.D.)	17.9	(16.9)	14.3	(19.7)	23.7	(21.8)
Cigarettes/day	(S.D.)	20.4	(11.0)	14.5	(11.1)	20.4	(10.0)
Education - n (%)							
≤ 8th grade		10	(5.7)	46	(66.7)	22	(43.1)
9-12 grade		126	(72.4)	22	(31.9)	26	(51.0)
>12th grade		38	(21.9)	1	(1.4)	3	(5.9)

Symptoms and Radiography (Internal Comparisons)

Tables 2 through 9 summarize the prevalence of cough, phlegm, shortness of breath, and pleural thickening by region, smoking, and exposure.

The prevalence of cough was 18 percent, 17 percent, and 27 percent in Montana, Texas, and North Carolina respectively. There were no apparent differences in the prevalence of cough among the three regions by age and smoking categories. Prevalence tended to increase with age (except North Carolina) and smoking (Table 2). There were no apparent differences in the prevalence of cough among the regions by exposure groups, and no apparent association of cough with exposure either within each region or when all regions were combined (Table 3).

The prevalence of phlegm was 18 percent, 17 percent, and 25 percent in Montana, Texas, and North Carolina respectively. There were no apparent differences in the prevalence among the three regions by age or smoking categories. Prevalence increased consistently with age only among ex-smokers. Except for Texas, the prevalence of phlegm was highest in smokers with ex-smokers intermediate (Table 4). There were no apparent differences in the prevalence of phlegm among the regions by exposure groups, and no apparent association of phlegm with exposure either within each region or when regions were combined (Table 5).

The prevalence of dyspnea was low compared to cough and phlegm: 4 percent, 9 percent, and 6 percent in Montana, Texas, and North Carolina respectively. There were no apparent differences among the regions by age or smoking categories. There was no apparent association of smoking with dyspnea (nonsmokers and ex-smokers had the highest prevalence). Dyspnea increased with age in all smoking categories (Table 6). There were no apparent differences in the prevalence of dyspnea among the regions by exposure groups, and no apparent association with years worked or cumulative exposure (Table 7).

The prevalence of pleural thickening was 4 percent, 13 percent, and 18 percent in Montana, Texas and North Carolina respectively, and was significantly less in Montana after adjustment for age or years worked. The number of those with bilateral pleural thickening* was 5 of 6, 4 of 9, and 6 of 9 in the three regions. There was no difference in the prevalence of bilateral pleural thickening among the three regions by age or smoking categories. Prevalence increased with age (there was 1 in the <40 year age group in Montana and 2 in the ≤ 40 year age group in North Carolina with bilateral pleural thickening), but the association of age and pleural thickening was significant only among smokers. There was no significant association of smoking and bilateral pleural thickening, although the prevalence was zero among nonsmokers, and highest among smokers (Table 8). There were no differences in prevalence among the regions by exposure group (except the medium

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*All the cases of pleural thickening were extent 1, except for one case each in the low and high cumulative exposure groups in Texas.

TABLE 2. PREVALENCE OF COUGH AMONG TALC WORKERS BY AGE, SMOKING, AND REGION

	Age		
	<40 % (95% C.I.)	≥40 % (95% C.I.)	Total % (95% C.I.)
Montana			
Nonsmoker	7	19	10 (4-21)
Ex-smoker	0	10	5 (0.05-17)*
Smoker	27	38	29 (19-40)*
Total	16 (10-24)	23 (13-35)	18 (13-25)
Texas			
Nonsmoker	10	25	14 (3-39)
Ex-smoker	11	40	26 (11-50)
Smoker	15	8	13 (5-28)
Total	13 (5-28)	23 (11-42)	17 (9-28)
North Carolina			
Nonsmoker	0	0	0 (0-25)
Ex-smoker	33	17	22 (4-56)
Smoker	38	37	38 (21-58)
Total	29 (13-51)	26 (12-45)	27 (15-42)
Total (All Regions)			
Nonsmoker	7 (2-16)	15 (5-32)	10 (5-20)*
Ex-smoker	7 (1-21)	19 (9-34)	13 (6-24)
Smoker	26 (18-35)	30 (18-45)	27 (20-35)*
Total	21 (15-29)	23 (15-32)	19

Cough = Answering yes to the question: "Do you usually cough on most days for as much as 3 months each year?"

Summary: No differences among regions by age and smoking.
Tendency to increase with age.
Smokers generally have the highest prevalence.

*95% C.I. do not overlap.

TABLE 3. PREVALENCE OF COUGH AMONG TALC WORKERS BY EXPOSURE AND REGION

	Montana % (95% C.I.)		Texas % (95% C.I.)		North Carolina % (95% C.I.)		Total (All regions) % (95% C.I.)	
Years Worked								
<5	17	(11-25)	20	(10-35)	30	(14-53)	19	(14-25)
5-9	14	(6-30)	18	(3-50)	33	(12-65)	19	(10-31)
≥10	30	(9-36)	0	(0-32)	20	(7-41)	21	(10-36)
Cumulative Exposure								
Low	15	(6-28)	7	(1-22)	19	(9-36)	14	(8-23)
Medium	17	(9-28)	31	(15-51)	50	(22-78)	25	(17-35)
High	17	(9-29)	11	(2-33)	22	(4-56)	16	(9-26)

Summary: No difference among regions by exposure.
No association with years worked.
No association with cumulative exposure.

TABLE 4. PREVALENCE OF PHLEGM AMONG TALC WORKERS BY AGE, SMOKING, AND REGION

	Age					
	<40 % (95% C.I.)		≥40 % (95% C.I.)		Total % (95% C.I.)	
Montana						
Nonsmoker	12		6		10	(4-21)
Ex-smoker	17		14		10	(6-30)
Smoker	27		23		26	(16-36)
Total	20	(13-29)	17	(8-29)	18	(13-26)
Texas						
Nonsmoker	20		25		21	(6-50)
Ex-smoker	22		40		32	(15-57)
Smoker	8		8		8	(2-21)
Total	14	(5-29)	23	(11-39)	17	(9-28)
North Carolina						
Nonsmoker	0		0		0	(0-25)
Ex-smoker	0		33		22	(4-56)
Smoker	23		42		34	(18-54)
Total	14	(4-34)	32	(16-51)	25	(14-40)
Total (All Regions)						
Nonsmoker	12	(5-24)	7	(1-22)	11	(5-20)*
Ex-smoker	13	(5-29)	27	(14-43)	21	(12-33)
Smoker	33	(24-43)	26	(15-40)	31	(24-39)*
Total	23	(16-30)	22	(15-31)	23	

Phlegm: Answering yes to the question: "Do you usually bring up phlegm from your chest for as much as three months each year?"

Summary: No difference among regions by age or smoking.
No association with age.
Smokers have highest prevalence.

*95% C.I. do not overlap.

TABLE 5. PREVALENCE OF PHLEGM AMONG TALC WORKERS BY EXPOSURE AND REGION

	Montana % (95% C.I.)	Texas % (95% C.I.)	North Carolina % (95% C.I.)	Total (All regions) % (95% C.I.)
Years Worked				
<5	19 (13-27)	20 (10-34)	20 (7-41)	19 (14-25)
5-9	12 (4-26)	9 (0.5-37)	33 (12-65)	16 (8-26)
≥10	30 (14-53)	13 (0.6-50)	25 (10-47)	25 (14-39)
Cumulative Exposure				
Low	17 (8-30)	7 (1-22)	13 (5-29)	13 (7-21)
Medium	18 (9-30)	27 (11-46)	50 (22-78)	24 (16-34)
High	17 (8-30)	17 (5-38)	33 (10-71)	19 (11-30)

Summary: No differences among regions by exposure.
No association with years worked.
No association with cumulative exposure.

TABLE 6. PREVALENCE OF DYSPNEA AMONG TALC WORKERS BY AGE, SMOKING, AND REGION

	Age					
	<40 % (95% C.I.)		≥ % (95% C.I.)		Total % (95% C.I.)	
Montana						
Nonsmoker	2		6		3	(0-11)
Ex-smoker	6		10		8	(2-21)
Smoker	2		5		2	(0-8)
Total	2	(0-6)	7	(2-16)	4	(2-9)
Texas						
Nonsmoker	10		25		14	(3-39)
Ex-smoker	0		20		11	(2-32)
Smoker	0		8		5	(0-16)
Total	2	(0-12)	19	(8-37)	9	(4-18)
North Carolina						
Nonsmoker	0		17		9	(0-37)
Ex-smoker	0		33		22	(4-56)
Smoker	0		0		0	(0-10)
Total	0	(0-14)	10	(3-24)	6	(1-17)
Total (All Regions)						
Nonsmoker	4	(0.5-13)	11	(3-27)	6	(2-14)
Ex-smoker	3	(0.2-16)	16	(1-18)	10	(4-20)
Smoker	1	(0-5)	6	(0-12.5)	3	(1-7)
Total	2	(0-5)*	10	(5-17.5)*	5	

Dyspnea = Answering yes to the question: "Do you get short of breath walking with people your own age on level ground?"

Summary: No differences among regions by age or smoking.
Increased prevalence with increased age.
No association with smoking.

*95% C.I. do not overlap.

TABLE 7. PREVALENCE OF DYSPNEA AMONG TALC WORKERS BY EXPOSURE AND REGION

	Montana % (95% C.I.)	Texas % (95% C.I.)	North Carolina % (95% C.I.)	Total (All regions) % (95% C.I.)
Years Worked				
<5	5 (3-12)	10 (4-22)	5 (0-22)	6 (3-10)
5-9	0 (0-9)	0 (0-25)	0 (0-24)	0 (0-6)
≥10	5 (0-22)	13 (0-50)	10 (2-29)	8 (2-20)
Cumulative Exposure				
Low	6 (1-16)	7 (1-22)	3 (0-17)	5 (2-11)
Medium	2 (0-7)	8 (1-23)	0 (0-27)	3 (1-8)
High	3 (0-11)	11 (2-33)	22 (4-56)	7 (2-14)

Summary: No differences among the regions by exposure.
No association with years worked.
No association with cumulative exposure.

TABLE 8. PREVALENCE OF BILATERAL PLEURAL THICKENING AMONG TALC WORKERS BY AGE, SMOKING AND REGION

	Age		
	<40 % (95% C.I.)	≥40 % (95% C.I.)	Total % (95% C.I.)
Montana			
Nonsmoker	0	0	0 (0-7.5)
Ex-smoker	0	5	4 (0-17)
Smoker	2	14	5 (1-13)
Total	1 (0-5)	7 (2-16)	3 (1-8)
Texas			
Nonsmoker	0	0	0 (0-27)
Ex-smoker	0	0	0 (0-17)
Smoker	0	33	11 (4-25)
Total	0 (0-9)	16 (6-34)	6 (2-15)
North Carolina			
Nonsmoker	0	0	0 (0-27)
Ex-smoker	33	0	11 (0-44)
Smoker	8	22	16 (7-32)
Total	10 (2-28)	14 (5-30)	12 (4.5-25)
Total (All Regions)			
Nonsmoker	0 (0-7)	0 (0-11)	0 (0-6)
Ex-smoker	6 (0.3-24)	3 (0-15)	4 (0-14)
Smoker	2 (0-7)*	22 (11-36)*	9 (5-15)
Total	2 (0-6)	11 (5-18)	5

Summary: No differences among regions by age and smoking.
Prevalence tends to increase with age.
No bilateral pleural thickening among nonsmokers.

*95% C.I. do not overlap.

TABLE 9. PREVALENCE OF BILATERAL PLEURAL THICKENING AMONG TALC WORKERS BY EXPOSURE AND REGION

	Montana % (95% C.I.)	Texas % (95% C.I.)	North Carolina % (95% C.I.)	Total (All regions) % (95% C.I.)
Years Worked				
<5	0 (0-4)	4 (0-14)	5 (0-22)	2 (0-5)
5-9	3 (0-14) *	9 (0-37)	0 (0-25)	3 (0-10) * *
≥10	22 (8-44)	14 (0-55)	26 (11-50)	23 (12-38)
Cumulative Exposure				
Low	2 (2-11)	4† (0-17)	6 (1-20)	4 (1-10)
Medium	0 (0-7) *	8 (1-23)*	30 (9-62)	5 (1-12)
High	7 (2-17)	6† (0-27)	13 (0-50)	8 (3-17)

Summary: No difference among regions by exposure except medium exposure group in North Carolina has a higher prevalence than medium exposure group in Montana.

Increased prevalence of bilateral pleural thickening with increasing years worked.

No association with cumulative exposure.

*95% C.I. do not overlap.

†Extent = 2.

exposure group in Montana was less than in North Carolina). Prevalence increased in all regions with increasing years worked, but was significant only for Montana and the combined regions. There was no association of bilateral pleural thickening with cumulative exposure (Table 9). There were no apparent differences in working experiences or respiratory disease between the regions among talc workers with and without pleural thickening. No worker showed pleural calcification on X-ray.

Table 10 compares workers with and without pleural thickening. Those with any pleural thickening were about 10 years older than those without. Workers with bilateral pleural thickening on average weighed more (11-15 Kg), had worked longer (6 years), and had higher average and cumulative exposures than those with unilateral or no pleural thickening. The average time between first exposure to talc and the date of the chest radiograph was 4.5 years for those with unilateral pleural thickening and 13.1 years for those with bilateral pleural thickening. The "latency" by region was 10 years for Montana and Texas and 17.7 years for North Carolina. All pulmonary function parameters of those with bilateral pleural thickening were reduced. Those with unilateral pleural thickening generally had intermediate lung function values.

Symptoms and Radiography (External Comparisons)

Table 11 summarizes the characteristics of the comparison populations. The coal miner populations were examined as part of the second round of the National Study of Coalworkers' Pneumoconiosis, and were divided into white males working only underground and only aboveground. The potash mines were part of the MSHA/NIOSH epidemiologic-industrial hygiene study of metal and nonmetal underground miners.[1,2] White male miners from 6 potash mines were used for comparison. All of the potash mines used diesel engines. The New York talc population were miners and millers of New York talc containing tremolite and anthophyllite.[3,4,5] The blue collar comparison population was part of the recently completed NIOSH blue collar control study and included male and female workers for such industries as electronics, synthetic textiles, bakeries and bottling plants.[6]

The workers in the comparison populations had worked longer in their current industry than had the study populations. The mining populations generally were heavier smokers than the study populations and the blue collar workers. All of the mining comparison groups had occupational exposures in the form of coal dust, diesel fumes and potash (primarily potassium chloride and sodium chloride), and talc containing asbestiform fibers.

Tables 12 through 15 summarize the age and smoking adjusted rates of cough, phlegm, dyspnea, and pleural thickening of the talc workers and comparison populations.

The prevalence of cough among the 40 or older workers in the study population was less than underground coal, and less than underground coal and New York talc when all ages were considered. There was no difference in the prevalence of cough of the study population and blue collar workers at either age level (Table 12).

TABLE 10. COMPARISON OF WORKERS WITH AND WITHOUT PLEURAL THICKENING (REGIONS COMBINED)

	No PT		Unilateral		Bilateral	
n	255		9		15	
Frequency (95% C.I.)						
Cough (%)	18	(14-23)	22	(4-56)	33	(14-63)
Phlegm (%)	18	(14-23)	22	(4-56)	33	(14-63)
Dyspnea ($\geq$ Grade 2)	5	(3-8)	11	(0-44)	7	(0-30)
Obliteration of costophrenic angle						
Unilateral	2	(0-5)	11	(0-44)	13	(2-37)
Bilateral	0.4	(0-1)	0	(0-29)	0	(0-19)
Means (S.E.)†						
Age	36.4	(0.8)	46.7	(3.4)	47.7	(2.2)
Height -cm	174.0	(0.5)	170.1	(2.1)	175.3	(2.0)
Weight -kg	76.6	(0.8)	80.5	(4.9)	91.9	(4.3)
Years worked	6.7	(0.4)	6.9	(2.2)	13.4	(2.3)
Cumulative exposure (mg/m^3 x years)	5.1	(0.4)	2.4	(0.7)	34.1	(24.6)
Average exposure (mg/m^3)	1.1	(0.1)	0.87	(0.3)	3.2	(2.5)
"Latency" -years	--		4.5	(1.4)	13.1	(2.3)
FEV_1/FVC x 100*	77.1	(0.7)	80.2	(2.7)	72.5	(2.2)
FEV_1 (L)*	3.56	(0.05)	3.47	(0.19)	3.08	(0.16)
FVC (L)*	4.61	(0.06)	4.29	(0.22)	4.19	(0.18)
Peak Flow (L/sec)*	8.37	(0.15)	7.62	(0.56)	7.02	(0.45)
FEF_{50}	4.10	(0.13)	4.19	(0.49)	3.30	(0.40)
FEF_{75}	1.40	(0.06)	1.45	(0.21)	1.24	(0.18)

†Lung function least square means adjusted for differences in sex, age, height, weight, and smoking status.

*Pleural thickening is a significant variable in the linear regression model.

TABLE 11. CHARACTERISTICS OF COMPARISON POPULATIONS FOR TALC STUDY

		New York Talc	Potash	Aboveground Coal	Underground Coal	Blue Collar Male	Blue Collar Female
n		121	875	509	5722	843	597
Age	(S.D.)	39 (12)	41 (13)	44 (12)	39 (13)	38 (14)	40 (13)
Height (cm)	(S.D.)	176 (6)	176 (6)	175 (6)	174 (6)	173 (7)	162 (6)
Years Worked (Range)	(S.D.)	11 (9) (0-33)	16 (13) (0-50)	18 (13) (0-55)	15 (13) (0-56)	12 (12) (0-50)	11 (10) (0-46)
Nonsmokers	(%)	21	20	22	21	25	49
Ex-Smokers	(%)	31	28	32	23	23	10
Mean Pack Years	(S.D.)	26 (28)	23 (20)	24 (19)	17 (18)	21 (23)	9 (10)
Mean Cigarettes/Day	(S.D.)	28 (19)	25 (14)	23 (12)	19 (12)	23 (15)	16 (12)
Smokers	(%)	48	52	46	56	52	42
Mean Pack Years	(S.D.)	26 (17)	28 (23)	27 (18)	17 (14)	23 (19)	17 (13)
Mean Cigarettes/Day	(S.D.)	27 (11)	25 (12)	22 (9)	17 (8)	23 (11)	19 (9)
Mean Current NO_2 Concentration (ppm)		N.A.	*0.90	N.A.	N.A.	N.A.	N.A.
Mean Current Total Dust (mg/m^3)		N.A.	*3.45	N.A.	N.A.	N.A.	N.A.
Respirable Dust		† 0.77 Mine † 0.87 Mill	N.A.	1.44 ††	1.36 ††	N.A.	N.A.
Fibers >5 µm/cc (LM)		† 5.4 Mine † 4.8 Mill	N.A. N.A.	N.A. N.A.	N.A. N.A.	N.A. N.A.	N.A. N.A.

* Personal samples, from Attfield (1978) and Sutton, et al. (1978)

N.A. = Not available

† From Dement, et al. (1980)

†† Collected between the first and second rounds of the National Coalworkers Study. The 25 coal mines were in both the first and second rounds of examinations of the coal study.

TABLE 12. COMPARATIVE RATES OF COUGH* AMONG TALC WORKERS COMPARED TO OTHER MINING POPULATIONS AND BLUE COLLAR WORKERS. STRATIFIED BY AGE AND INDIRECTLY ADJUSTED FOR SMOKING.

	A G E		
	<40 % (95% C.I.)	≥40 % (95% C.I.)	TOTAL % (95% C.I.)
Montana	16.7 (10-25)	24.1 (14-37)	20.1 (14-27)
Texas	13.6 (5-29)	21.8 (11-42)	17.4 (9-28)
North Carolina	28.6 (13-51)	23.5 (10-40)	26.2 (15-40)
Combined Study Population	17.4 (12-24)	23.7 (16-33)	20.3 (15.5-25)
New York Talc	36.2 (24-50	36.0 (24-50)	36.1 (28-45)
Potash Miners	20.5 (17-25)	28.3 (24-32)	24.1 (20-27)
Underground Coal	18.1 (16-20)	44.9 (43-46)	30.5 (29-32)
Aboveground Coal	16.0 (11-23)	35.3 (30-41)	24.9 (22-29)
Blue Collar	15.2 (11-18)	18.5 (15-23)	16.7 (14-20)

*Cough = Answering yes to the question: "Do you usually cough on most days for as much as three months each year?"

Summary:

<40: Study populations no different than comparison populations.

≥40: Montana, Texas, and North Carolina <<underground coal.

Total: Montana and Texas <<New York talc and underground coal.
Combined study population <<New York talc and underground coal workers.

TABLE 13. COMPARATIVE RATES OF PHLEGM[a] AMONG TALC WORKERS COMPARED TO OTHER MINING POPULATIONS AND BLUE COLLAR WORKERS. STRATIFIED BY AGE AND INDIRECTLY ADJUSTED FOR SMOKING

	Age		
	<40 % (95% C.I.)	≥40 % (95% C.I.)	Total % (95% C.I.)
Montana talc	20.2 (14-29)	18.5 (10-31)	19.4 (14-26)
Texas talc	13.8 (5-29)	21.8 (11-42)	17.5 (9-28)
North Carolina talc	12.9 (4-34)	31.6 (18-52)	21.5 (11-35)
Combined study population	17.8 (13-25)	23.2 (15-32)	20.3 (16-25)
New York talc	33.0 (22-47)	38.5 (26-53)	35.5 (27-45)
Potash miners	25.4 (21-29)	34.3 (30-38)	29.5 (27-34)
Underground coal	32.7 (31-35)	50.0 (46-53)	40.7 (39-41)
Aboveground coal	18.6 (13-26)	40.7 (35-47)	28.8 (25-33)
Blue collar	16.2 (13-19)	18.5 (15-24)	17.3 (14-21)

[a] Phlegm = Answering yes to the question: "Do you usually bring up phlegm for as much as 3 months each year?"

SUMMARY:

<40: Montana and Texas <<underground coal.
Combined study population <<underground coal.
≥40: Montana talc <<coal workers.
Texas <<underground coal.
Combined study population <<coal workers.

TOTAL: Montana <<New York talc, potash, underground coal.
Texas and North Carolina <<underground coal.
Combined study populations <<New York talc, potash, and coal workers.

TABLE 14. COMPARATIVE RATES OF DYSPNEA[a] AMONG TALC WORKERS COMPARED TO OTHER MINING POPULATIONS AND BLUE COLLAR WORKERS. STRATIFIED BY AGE AND INDIRECTLY ADJUSTED FOR SMOKING

	Age		
	<40 % (95% C.I.)	≥40 % (95% C.I.)	Total % (95% C.I.)
Montana	2.6 (2- 7)	6.4 (2-16)	4.4 (2- 9)
Texas	2.3 (0-13)	19.3 (8-37)	10.1 (4-20)
North Carolina	0 (0-14)	14.0 (5-29)	6.5 (2-18)
Combined study population	2.1 (0.5-5.5)	10.1 (5-17)	5.8 (4-10)
New York talc	6.8 (2-16)	18.6 (10-30)	12.3 (7-19)
Potash	5.4 (3- 7)	11.9 (9-15)	8.4 (6-11)
Underground coal	9.8 (9-11)	40.5 (39-43)	24.0 (23-25)
Aboveground coal	1.9 (0- 6)	28.0 (22-34)	13.9 (12-17)
Blue collar	4.7 (3- 7)	10.7 (8-15)	7.5 (6-10)

[a] Dyspnea = Answering yes to the question: "Do you get short of breath walking with other people of your own age on level ground?"

SUMMARY:

<40: Montana <<underground coal.
Combined study population <<underground coal.

≥40: Montana <<coal workers.
Texas and North Carolina <<underground coal workers.
Combined study population <<coal workers.

TOTAL: Montana <<coal workers.
Texas and North Carolina <<underground coal workers.
Combined study population <<coal workers.

TABLE 15. COMPARATIVE RATES OF BILATERAL PLEURAL THICKENING AMONG TALC WORKERS COMPARED TO OTHER MINING POPULATIONS AND BLUE COLLAR WORKERS. STRATIFIED BY AGE AND INDIRECTLY ADJUSTED FOR SMOKING

	Age		
	<40 % (95% C.I.)	≥40 % (95% C.I.)	Total % (95% C.I.)
Montana	1.1 (0- 5)	8.7 (3-19)	4.7 (2-10)
Texas	0 (0- 9)	16.4 (6-34)	7.8 (3-18)
North Carolina	9.8 (2-28)	10.9 (3-25)	10.3 (4-22)
Combined study population	1.5 (0- 5)	11.5 (6-20)	6.3 (3- 9)
New York talc	0 (0- 6)	16.6 (8-29)	7.9 (4-15)
Potash	0 (0- 1)	0.4 (0- 1)	0.2 (0-0.5)
Underground coal	0 (0-0.5)	0.1 (0-0.2)	0.1 (0-0.2)
Aboveground coal	0 (0- 3)	0.3 (0- 1)	0.1 (0-0.5)
Blue collar	0.4 (0- 1)	0.3 (0- 1)	0.4 (0- 1)

SUMMARY:

<40: North Carolina talc >>all nontalc populations, except aboveground coal.

≥40: All talc populations >>all nontalc populations.

TOTAL: All talc populations >>all nontalc populations.

The prevalence of phlegm was generally less in both age groups among the study population compared to the aboveground coal workers. Overall the combined study populations had less phlegm than all the comparison populations except blue collar workers (Table 13).

The prevalence of dyspnea among the study population was less than underground coal workers at all ages, and less than aboveground coal workers in the older age group and when all ages were considered. There were no differences in prevalence when compared to New York talc, potash, and blue collar workers; in fact the frequency was generally lower in the study populations than all of the comparison populations (Table 14).

In summary, the prevalence of cough, phlegm, and dyspnea was not elevated in comparison to potash miners and blue collar workers, and after adjustment for age and smoking.

Table 15 summarizes the comparative rates of bilateral pleural thickening. Except for North Carolina where the prevalence of pleural thickening was 10 percent and higher than all nontalc populations, the rates were low in the less than 40 years of age groups. In the 40 or greater year age groups the prevalence of bilateral pleural thickening remained low (less than 1 percent) in the nontalc comparison population, but was significantly higher in all the talc populations, ranging from 9 percent in Montana to 17 percent in the New York talc population. Overall adjusted rates in all the talc populations were elevated compared to the nontalc comparison populations.

Pulmonary Function (Internal Comparisons)

Table 16 summarizes the results of multiple regression models of pulmonary function with the predicator variables race, sex, age, height, smoking status, region, department, years worked, and cumulative exposure. Age and height were significant for all parameters (except for FEV percent). Race, department, years worked, and cumulative exposure were not significant for any of the lung function tests. Sex, smoking status, and region were significant for some parameters. A multiple regression model without race and department produced similar results although cumulative exposure achieves statistical significance for FVC. Mean adjusted values by sex, smoking status, and region are summarized in Table 17.

Pulmonary Function (External Comparisons)

Table 18 summarizes the mean percent predicted pulmonary function of the study population compared to potash and coal (males only) and blue collar workers (male and female). The study population of talc workers had reduced FEV_1, FVC, FEF_{50} and FEF_{75} compared to both coal populations. Flow rates (peak flow, FEF_{50}, FEF_{75}) of the talc workers were reduced compared to the potash and blue collar workers, but there were no differences in FEV_1 and FVC.

Regression models with observed/predicted lung function as dependent variables and age, smoking status, region, department, and exposure as independent variables were significant only for percent predicted FVC and FEF_{75}. The study population (Montana, Texas, and North Carolina combined) was estimated to show

TABLE 16. SUMMARY OF MULTIPLE REGRESSION MODEL FOR LUNG FUNCTION OF ALL TALC WORKERS - REGRESSION MODEL:

$$PFT = \alpha + \beta_1 \text{ (race)} + \beta_2 \text{ (sex)} + \beta_3 \text{ (age)} + \beta_4 \text{ (height)} + \beta_5 \text{ (smoking status)} + \beta_6 \text{ (region)} + \beta_7 \text{ (department)} + \beta_8 \text{ (years exposure)} + \beta_9 \text{ (cumulative exposure)}$$

	Race	Sex	Age β_3 (S.E.)	Height (cm) β_4 (S.E.)	Smoking status	Region	Department	Years exposure β_8 (S.E.)	Cumulative exposure β_9 (S.E.)	r
FEV_1% (%)	N.S.	N.S.	a -0.40 (0.04)	N.S. -0.09 (0.07)	a	a	N.S.	N.S. -0.04 (0.08)	N.S. +0.01 (0.02)	0.60
FEV_1 (mL)	N.S.	a	a -32 (3)	a +45 (6)	b	N.S.	N.S.	N.S. -7 (6)	N.S. -2 (2)	0.80
FVC (mL)	N.S.	a	a -19 (4)	a +64 (6)	N.S.	b	N.S.	N.S. -4 (7)	N.S. -4 (2)	0.31
Peak flow (mL/sec)	N.S.	a	a -50 (9)	a +79 (15)	a	N.S.	N.S.	N.S. +0.7 (17)	N.S. -4 (4)	0.68
FEF_{50} (mL/sec)	N.S.	N.S.	a -61 (8)	b +29 (13)	b	N.S.	N.S.	N.S. -10 (15)	N.S. +2 (3)	0.58
FEF_{75} (mL/sec)	N.S.	N.S.	a -40 (4)	b +12 (6)	b	N.S.	N.S.	N.S. -5 (6)	N.S. -1 (2)	0.71

N.S. = $p>0.05$

a = $p<0.01$

b = $p<0.05>0.01$

TABLE 17. LEAST SQUARES ADJUSTED PULMONARY FUNCTION MEANS OF TALC WORKERS BY SEX, SMOKING STATUS, AND REGION, CALCULATED FROM MODEL:

$$\text{PULMONARY FUNCTION} = \alpha + \beta_1\ (\text{sex}) + \beta_2\ (\text{age}) + \beta_3\ (\text{height}) + \beta_4\ (\text{smoking status}) + \beta_5\ (\text{region}) + \beta_6\ (\text{years worked}) + \beta_7\ (\text{cumulative exposure})$$

	FEV% % (S.E.)	FEV_1 L (S.E.)	FVC L (S.E.)	Peak flow L (S.E.)	FEF_{50} L (S.E.)	FEF_{75} L (S.E.)
Sex						
Male	78.1 (0.6)	3.85 (0.04)	4.94 (0.05)	9.04 (0.12)	4.53 (0.10)	1.55 (0.05)
Female	80.0 (1.6)	3.35 (0.12)[a]	4.17 (0.14)[a]	7.51 (0.34)[a]	4.26 (0.29)	1.41 (0.13)
Smoking Status						
Nonsmoker	80.4 (1.1)	3.71 (0.08)	4.62 (0.09)	8.31 (0.23)	4.55 (0.19)	1.63 (0.09)
Ex-smoker	79.6 (1.2)	3.58 (0.09)	4.51 (0.10)	8.60 (0.25)	4.52 (0.21)	1.44 (0.10)
Smoker	77.2 (1.0)	3.51 (0.07)	4.53 (0.08)	7.93 (0.20)	4.12 (0.17)	1.37 (0.08)
Region						
Montana	76.8 (0.7)	3.58 (0.06)	4.65 (0.06)	8.51 (0.16)	4.07 (0.13)	1.41 (0.06)
Texas	79.9 (1.3)	3.51 (0.10)	4.39 (0.11)	8.46 (0.27)	4.63 (0.23)	1.48 (0.10)
North Carolina	80.5 (1.3)	3.71 (0.10)	4.62 (0.11)	7.87 (0.28)	4.48 (0.24)	1.55 (0.11)

$FEV\% = (FEV_1/FVC) \times 100$.

[a] 95% C.I. do not overlap.

TABLE 18. MEAN PERCENT PREDICTED PULMONARY FUNCTION OF MONTANA, TEXAS, NORTH CAROLINA TALC WORKERS COMPARED TO MINER AND BLUE COLLAR COMPARISON GROUPS, ADJUSTED FOR AGE, HEIGHT AND SMOKING

	% Predicted pulmonary function = (observed/predicted) x 100				
	FEV_1	FVC	Peak flow	FEF_{50}	FEF_{75}
Comparison Populations					
Males Only (n = 251)					
Potash	98.85 (1.01)	99.60 (0.84)	93.19 (1.03)[a]	95.62 (2.10)[a]	88.23 (3.12)[a]
Underground coal	97.55 (1.01)[a]	95.09 (0.80)[a]	100.19 (1.13)	95.62 (2.17)[a]	82.58 (2.75)[a]
Aboveground coal	96.60 (1.01)[a]	96.62 (0.83)[a]	112.43 (1.29)[b]	92.93 (2.00)[a]	80.76 (3.92)[a]
Males and Females (n = 292)					
Blue collar	99.71 (0.95)	101.00 (0.78)	97.85 (1.04)[a]	94.12 (2.02)[a]	84.54 (2.41)[a]

a = >2 S.E. less than 100, assuming no variation in prediction values.

b = >2 S.E. greater than 100, assuming no variation in prediction values.

a reduction in FVC of about 0.25 percent less per year than the coal and potash populations. Cumulative exposure had a statistically significant coefficient of -0.07 percent ($mg/m^3 \times$ years). Ex-smokers in the study population consistently had reduced FVC compared to the aboveground coal and blue collar populations, while all smoking categories were reduced compared to underground coal. Percent predicted FVC was reduced in Texas when compared to all populations except potash miners. Percent predicted FVC was reduced in Montana only when compared to underground coal, and was reduced in North Carolina only when compared to underground and aboveground coal workers.

Percent predicted FEF_{75} in the study population decreased about 2 percent faster/year than the coal and potash populations, but increased about 1.5 percent for each year worked. Smoking, region, department and cumulative exposure were not significant.

DISCUSSION

Interpretation of the data from this study has the inherent problems of all cross-sectional prevalence studies. The workers examined in this study comprise only those currently working. While there are few studies that have examined ex-workers to determine the effect of selection, significant disease has been observed among older ex-hemp workers[7] and progressive massive fibrosis among ex-workers in two silica flour mills.[8] In both of these studies there was significant disease among the currently employed workers. The consequences of not examining ex-workers in this study are unknown.

The length of the study group's working history, however, is a relatively short time for the development of occupationally related symptoms, radiographic changes, and impaired lung function that might be caused by exposure to a mineral dust. Significant changes in FEV_1 and FVC due to exposure to respiratory irritants (such as cigarette smoke) may not become noticeable until after 20 to 30 years of smoking. Essentially the same time interval may be required for the development of pneumoconiosis.[9] The mean ages of the study populations were around 40, and mean exposure to talc dust was less than 10 years. Therefore, if talc dust were to adversely affect FEV_1 and FVC, the lung function results might not reflect that effect because of the short exposure times (unless the biological reactivity of talc and cigarette smoke is different).

Estimating past exposure was a problem in this as in other studies where there was no historical environmental data. Although dust levels are assumed not to have changed substantially with time, past exposure could be higher or lower than the calculated estimates and obscure a true dose-response relation if it existed. For example, if the estimates were higher than actual exposure, a true association could be obscured because of fewer workers with "disease" in the higher exposure group. If the estimate was lower than actual, an association could be obscured because of more workers with "disease" in the lower exposure groups. While years worked is an exact time period, it may be a less accurate measure of overall exposure than the calculated estimate of cumulative exposure. Oftentimes the two are confounded as three may be a high correlation of years worked with exposure. This was not true for Texas but there was an association of years worked and cumulative exposure in Montana and North Carolina. Age is also generally correlated with exposure (years worked and cumulative exposure). In this study they were significantly correlated, except for age and cumulative exposure in Texas. Although statistically significant, the correlations were not large. Thus for example, the years worked sum of squares in the lung function regression models did not change very much when adjusted for cumulative exposure and age.

Controls, or comparison populations, are always of concern. In this report, two comparisons were utilized. One was an internal comparison, i.e., dose-response relationships, looking at the association of morbidity in workers with high and low exposures within the study population. The second compares the morbidity of the study population with the morbidity of the control populations.

The advantages of the internal comparisons are that the variability from measurement error, variability due to external factors such as season, differences in the survey team, etc., are minimal. A disadvantage is that the estimates of long-term exposures are not verifiable and may obscure a dose-response relation. Also internal comparisons do not allow for an assessment as to whether the prevalence of abnormalities are different than would be expected if there were no work exposures.

For categorical parameters the groups were stratified by age and smoking to look for effects of these potentially confounding variables before examining their association with exposure variables. For continuous variables these parameters were included in the regression equations. There was no consistent association of increased symptoms, bilateral pleural thickening, or decreased pulmonary function associated with either of the exposure variables. This lack of a dose-response association is consistent with the finding of no differences among the regions in the prevalence of symptoms despite the differences in environmental dust levels. The differences among the regions in the prevalence of bilateral pleural thickening were not large, and the tendency to increase with exposure was somewhat confounded with the tendency for the prevalence to also increase with age.

There was no association of dust levels or years worked with any of the lung function parameters, except for FVC. There were no convincing regional differences in lung function, although FVC was reduced in Texas compared to both North Carolina and Montana. FVC was 0.23L and 0.26L less in Texas than in North Carolina and Montana after adjustments for differences in sex, age, height, smoking, and exposure. Without adjusting for exposure, the differences in FVC were 0.60L and 0.61L for North Carolina and Montana respectively. Thus the exposure adjustments reduced the regional FVC differences by about 60 percent. In Texas then, dust exposure was associated with a mean loss of about 360 ml (or an average of about 67 ml/year). Reduction in FVC was dose related in one model but not the other, and was estimated as -4 ml for each unit of cumulative exposure. Multiplying the average cumulative exposure in each region times the estimated loss in FVC for each cumulative exposure unit shows that the calculated average loss in FVC resulting from talc dust exposure was -23.6 ml in Montana, -45.2 ml in Texas, and -12 ml in North Carolina. Maximum loss in each region was estimated to be -224 ml in Montana, -1496 ml (1.5L) in Texas, and -84 ml in North Carolina. The biological significance of these estimated mean losses are minimal except for the very high exposures in Texas.

The internal comparisons showed that age was consistently associated with increased prevalence of cough, dyspnea, and decreased pulmonary function. The calculated loss of pulmonary function with age was comparable to values from other cross-sectional studies[11,12] and there was little difference in the age coefficients among the regions. The relationship between smoking and pulmonary function was as might be expected. Smokers generally had the poorest values, and nonsmokers the best.

The second way to attempt to control for confounding variables and to estimate whether there is elevated morbidity is to compare the study population with some other population or populations. The ideal (which is never achieved) is to compare the study population with another population that is identical in every respect except exposure. Since in this study local comparison populations were not available, workers examined by NIOSH in other studies were used for comparison. The comparison populations were examined using the same basic protocol so that measurement error is probably reduced. Each population has certain advantages and certain disadvantages; for example, the coal and potash workers are miners, but are not unexposed. The blue collar workers are a population thought to be unexposed to respiratory irritants, but they are not miners.

There are several reasons for using multiple comparison populations. No comparison population is ideal, and several may help in interpretation of the data. Several factors may affect comparative morbidity that are not related to work exposure; but are not measured. They include region, socioeconomic status, type of employment (for example, mining), weather, season, technician, etc. It is not likely that several comparison populations will all have biases in the same direction relative to the study population. Thus consistent differences between the study and comparison populations gives one more confidence that the differences are not the result of unknown or unmeasured variables.

There was little difference in the prevalence of cough, phlegm, and dyspnea among the talc study population, potash miners, aboveground miners, and blue collar workers. (Older aboveground coal workers had an elevated prevalence of dyspnea.) New York talc workers and underground coal miners consistently had elevated symptoms rates. Predicted FEV_1 and FVC was reduced 2 to 5 percent below predicted when compared to the two coal mining populations, and after adjustments for age, height, and smoking. Interestingly, FEV_1 and FVC of the study population were not reduced compared to potash miners, or blue collar workers; neither of which is believed to have occupational exposures known to reduce lung function. As neither exposure variable was significant, it seems unlikely that exposure was causing the differences in lung function between the study and comparison populations. Although statistically significant, the mean differences in adjusted FEV_1 and FVC between the study and coal populations were not large. Substantial reductions in FEV_1 and FVC are of concern because several studies have shown them to be related to risk of death (although not necessarily death from respiratory disease) (Becklake and Permutt, 1979), but the small reductions in FEV_1 and FVC seen in this study are not of the magnitude to cause this type of concern. This conclusion must be qualified because of the short exposure time, however.

Flow rates at low lung volumes (FEF_{50} and FEF_{75}) in the study population were less than 100 when compared to other miners and blue collar workers. FEF_{50} was better than 90 percent of predicted, while FEF_{75} was between 80 and 90 percent. Air flow at low lung volumes is considered to be measuring changes occurring primarily in the small airways (Hyatt, et al., 1979; Mead, 1979). A current hypothesis of the pathophysiology of chronic air flow obstruction is that changes in lung function seen in disease such as emphysema start in the region of the small airways.[14,15] Tests such as FEF_{50} and FEF_{75} are of interest because it is difficult to detect pathophysiologic changes in the small airways that may be occurring for unknown time periods before they become evident in more routine tests such as FEV_1 and FVC. While existing data (such as the ability of FEF_{50} and FEF_{75} to detect differences in high and low risk groups) are compatible with the idea that air flow obstruction begins in the small airways, there are no available prospective data to prove it. Therefore, the significance of these reductions is only suggestive.

Peak flow was reduced in the study population compared to potash and blue collar workers, was no different than underground coal miners, and was elevated compared to aboveground and coal workers. Peak flows are most sensitive to changes in large airways, but are also most subject to technician differences and subject effort. The prognostic significance of reduced peak flow is also not known.

The most surprising finding in this study was the prevalence of pleural thickening. Asbestos (particularly anthophyllite) from either occupational or community exposure is associated with an increased prevalence of pleural thickening.[16] Talc contaminated with asbestos (tremolite and anthophyllite) seen under the light and electron microscope has also been associated with an increased prevalence of pleural thickening.[3] But studies of workers exposed to talc without significant asbestos content have reported radiographic changes characteristic of pneumoconiosis,[17,18,19] rather than pleural abnormalities, and excessive mortality from nonmalignant respiratory disease (supported by radiographic evidence).[33] The prevalence of pneumoconiosis, however, was not significant in this study. Pleural abnormalities (unspecified) were found in 9 percent of Vermont talc workers[20] compared to [illegible] percent with small irregular opacities and 12 percent with small rounded opacities. This is in contrast to this study where pleural thickening was observed in 9 percent of the population, but less than 1 percent had pneumoconiosis.

Pleural thickening due to asbestos exposure is generally considered to take many years to develop. In a study of a Swedish population, mean latency for the development of bilateral pleural plaques after first exposure to asbestos was estimated at about 30 years and pleural plaques were rare before age 40.[21] However, Ochs and Smith[22] reported on at least one case where as little a time interval as one year was necessary for the appearance of bilateral pleural thickening in an individual without occupational asbestos exposure. In the study reported here, latency (time between first known talc exposure and date of the study) was 13 years for workers with bilateral pleural thickening and 4.5 years in those with unilateral thickening, a much shorter time than generally associated with asbestos exposure.

The prevalence of pleural thickening may vary considerably. In a Swedish study about 1 percent of the men over 40 and less than 0.1 percent in men less than 40 had bilateral pleural plaques.[21] Almost 80 percent were current or ex-smokers and had had some exposure to asbestos. Fibrosis was rare (4 percent of those with pleural thickening). Another community type study in Birmingham, England[23] found that about 7 percent of those attending chest clinics had pleural plaques (10 percent of these were calcified). Unilateral obliteration of the costophrenic angle (not considered to be caused by asbestos) was observed in 36 percent of those with pleural plaques, and there was a definite history of asbestos exposure in no more than 11 percent of the cases. Much of the pleural thickening was considered to be due to pleural disease (39 percent of those with pleural abnormality reported having had emphysema, several chest wall injuries, two or more attacks of pleurisy, compared to 12 percent of the controls). Single attacks of pleurisy were considered as having only a slight likelihood of producing pleural thickening. In the study of talc workers reported here there was no obvious difference between those with and without pleural thickening in the exposure to asbestos or in chest disease.

In these two community studies, the association of pleural thickening was quite different, and was not necessarily related to asbestos exposure. The association with pleural thickening may in fact be incidental as the prevalence of pleural thickening may be quite different in asbestos exposed workers. For example, prevalences of 17.5 percent and 35 percent have been reported in asbestos manufacturing plants and shipyard joiners.[24,25] Two other studies of shipyard and dockyard workers reported prevalence of pleural thickening around 5 percent.[24,26] It is possible that factors other than asbestos (both the type and magnitude of exposure) may account for these differences (e.g., age distribution; method of reading X-rays, oblique X-rays in addition to PA; incidence of tuberculosis; bacterial or viral infections; smoking habits).

Exposure to other dusts may also be associated with pleural abnormalities. Smith[27] reported finding pleural calcification among 1.5 percent of 197 bakelite insulators, 1.7 percent of 114 calcimine workers, 1.6 percent of 302 men making mica insulators, and 6.3 percent of miners and millers exposed to tremolitic talc, but none in 261 asbestos workers. Smith[27] comments that the common feature of exposure of all four groups with pleural calcification was exposure to talc and/or mica. Thus while pleural thickening is said to be a signpost of asbestos exposure,[16] other agents have been associated with pleural thickening in the absence of known asbestos exposure. Because no asbestos was found nor thought to be associated with Montana and North Carolina talc, these results suggest that talc itself may be capable of causing the pleural changes. It is also possible that there are pockets of asbestos in the talc deposits, that could result in asbestos exposure sufficient to produce pleural changes.

We do not have available a detailed clinical history to evaluate the possibility of chest injury or disease producing the pleural thickening in these populations. If such conditions were causative, they would be more likely to produce unilateral rather than bilateral thickening. We have therefore looked at the association of exposure with bilateral pleural thickening which is more likely than unilateral to be occupational in origin.

When we do so, the association with talc exposure remains. And in the populations over 40 there was no statistical difference in the prevalence of bilateral pleural thickening irrespective of the purity of the talc. It is possible that there was a difference in the radiographic interpretation (different reader, calendar year, weight difference in those with and without pleural thickening). Evaluation of this potential bias is currently under investigation. Until that study is completed, the most likely explanation for the increased prevalence of pleural thickening is the exposure to talc.

The clinical significance of pleural thickening, pleural plaques, and pleural calcification as a result of asbestos exposure remains unclear, but is of concern because the pleural changes are considered to represent a significant exposure to asbestos and may be related to mesothelioma. The suggestion[28] that talc is possibly carcinogenic may be due to asbestos contamination of the talc. The characteristics of talc have mostly been poorly reported. Talc free of asbestos contamination does not appear to increase the risk of cancer, and mesothelioma has not been associated with talc exposure.[29,30,31,32] Risk of cancer in this study cannot be determined. Although lung function is somewhat reduced in those with bilateral pleural thickening, the biological significance of pleural changes in the talc populations of this study is also unclear.

CONCLUSIONS

In this cross-sectional study of 299 talc workers from Montana, Texas, and North Carolina, there was no association of symptoms (cough, phlegm, dyspnea) or reduced lung function with exposure. The prevalence of symptoms was not elevated and there was no difference in FEV_1 and FVC compared to the potash and blue collar control populations. Minimal (but statistically significant) reductions occurred in comparison with coal workers. Thus both internal and external comparisons were generally consistent in confirming the lack of an association between exposure and morbidity. While there were no differences in the symptom prevalences among the three talc regions (despite differences in exposure and talc composition), there were differences in the prevalence of cough and phlegm between the study population and the workers exposed to talc containing tremolite and anthophyllite.

The major significant health effect observed in this study was the increased prevalence of bilateral pleural thickening. The excess was considerable in relation to the nontalc comparison populations, but the dose-response relationships were somewhat confounded with age. The similar results with the New York talc population, the lack of a consistent association of pleural thickening with asbestos exposure, and the lack of parenchymal changes in the talc exposed workers suggest the possibility that talc was an etiological agent in the development of bilateral pleural thickening. The long term significance is unclear. While those with bilateral pleural thickening had some reduction in lung function and a possible increase in symptoms, the clinical effects were mild. The concern as to whether pleural thickening is a precursor of mesothelioma remains unanswered. This would appear unlikely because of no reported mesotheliomas associated with talc exposure.

Several points seem relevant to interpreting the results. The exposure times are relatively short. Therefore more time may be needed to see exposure effects. The reduced flow rates of low lung volumes supports this caution, as they may be early indicators of airways disease. On the other hand, the association of talc exposure with bilateral pleural thickening is occurring after shorter latency periods than is commonly found among asbestos workers and is associated with some loss in lung function, but no apparent disability. A prospective study seems necessary to answer the question concerning long term effects of exposure to talc, and the prognostic significance of pleural thickening.

INDUSTRIAL HYGIENE PORTION

INTRODUCTION

Talc, a magnesium silicate mineral, is mined in several geographic areas in the United States. The ore bodies examined in this study were Montana, Texas, and North Carolina. We examined seven mines and eight mills.

The purpose of the study was to characterize the talc, evaluate the workers' exposure, and ascertain the chronic effects of exposure (Table 19). The environment of each facility was characterized as to total and respirable dust concentrations, percent free silica, trace element concentrations, percent fibrous minerals, calcite, and dolomite. Individual exposure was determined by personal respirable breathing zone samples on all participating employees. Estimates of exposure for each job were obtained from the personal samples.

TABLE 19. INDUSTRIAL HYGIENE CHARACTERIZATION OF TALC

I.	Personal Respirable Breathing Zone Samples
II.	Trace Element Concentration
III.	Mineral Composition
IV.	Fibrous Minerals
V.	Free Silica

The mines in Montana and Texas are typical open-pit operations, while the mine examined in North Carolina is underground employing square set timbers and stopes.

RESULTS

Personal respirable breathing zone samples (PRBZ) were collected from each participating employee and time weighted averages (TWA) were obtained. The TWA's were utilized to derive geometric mean values for each job examined. These mean values were then used to develop cumulative exposures.

The time weighted averages for each employee were grouped together according to the actual job performed on the day of the study. The geometric mean for each job classification was then calculated from the grouped TWAs.

The geometric mean for the dust levels in the mine and mill are presented by region (Table 20 and 21).

Each ore body was analyzed for the following trace elements: Iron, manganese, calcium, aluminum, zinc, and nickel (Table 22). These trace elements were selected to compare the talc examined in this study with the talc examined in New York and Vermont.

TABLE 20. PERSONAL RESPIRABLE BREATHING ZONE SAMPLES (AVG = GEOMETRIC MEAN)

Job	Avg (mg/m^3)	Variance	Number of Samples
Montana			
Bagger	2.8	1.9	29
Labman	.3	2.5	4
Fork Lift Op.	.5	1.8	5
Mill Operator	1.0	2.5	7
Laborer	1.4	2.0	6
Foreman	.6	2.8	14
Boiler Operator	.1	4.9	2
Front-End Op.	.8	6.1	14
Maintenance	.4	4.3	16
Welder	6.3	----	1
Wash Plant Op.	1.4	8.7	2
Sorter	1.6	2.3	50
Driller	.1	----	1
Truck Driver	.3	1.8	15
Miner	.4	1.9	2
Shovel Operator	.2	3.6	5
Calciner Operator	.6	----	1
	.86	.59	174
Texas			
Bagger	3.1	2.9	3
Stacker	1.6	----	1
Forklift Op.	2.3	1.5	2
Mill Operator	38.4	----	1
Laborer	1.3	4.5	10
Foreman	1.3	3.6	4
Front-End Op.	1.3	5.3	7
Maintenance	1.0	3.6	10
Sorter	.6	1.8	2
Driller	.7	2.0	2

(continued)

TABLE 20 (continued).

Job	Avg (mg/m^3)	Variance	Number of Samples
Texas			
Truck Driver	.9	1.5	5
Miner	.1	1.5	2
Shovel Operator	.3	1.2	2
Calciner Operator	1.1	----	1
Crusher Operator	1.7	----	1
Welder	8.5	----	1
	1.08	.52	54
North Carolina			
Bagger	.9	----	1
Mill Operator	.9	----	1
Laborer	.2	5.8	9
Foreman	.9	----	1
Maintenance	.03	5.8	2
Driller	.1	1.4	3
Hoist Operator	.1	2.2	2
Miner	.3	4.2	9
Grader	.4	4.8	7
Packer	1.2	----	1
Cutter	1.2	2.5	4
Rounder	.9	----	1
Officer Personnel	.1	16.5	3
	.21	.74	44
ALL REGIONS	.72	.68	275

TABLE 21. SUMMARY OF RESPIRABLE DUST SAMPLES
(AVG = GEOMETRIC MEAN)

Region	Avg (mg/m^3)	95% Confidence Range of Mean
Montana		
Mill	1.1	.85 - 1.41
Mine	.66	.47 - .92
Texas		
Mill	1.56	2.54 - .96
Mine	.45	.18 - .71
North Carolina		
Mill	.26	.13 - .51
Mine	.14	.07 - .31

CONCLUSIONS

Mill - Baggers and Mill Operators had highest exposures.

Mine - Truck Drivers and Front-end Loader Operators had highest exposure.

TABLE 22. TRACE METALS (mg/m^3)

Montana

Iron	Manganese	Calcium	Aluminum	Zinc	Nickel
.05	<.01	.05	.2	<.01	<.01
Limit of Detection					
.01	.01	.03	.1	.01	.01

North Carolina

Iron	Manganese	Calcium	Aluminum	Zinc	Nickel
.05	<.02	.05	.2	<.02	<.02
Limits of Detection					
.02	.02	.02	.04	.02	.02

Texas

Iron	Manganese	Calcium	Aluminum	Zinc	Nickel
.5	<.08	8.0	.04	.08	<.08
Limits of Detection					
.1	.08	.2	.2	.08	.08

Montana talc had the lowest concentrations of trace elements of the three regions examined. The trace element concentrations were slightly higher in North Carolina. Texas talc differed most significantly from the other regions by its extremely large concentration of calcium.

The mineral composition of bulk samples also indicated higher calcium value in Texas. This talc had a much larger percentage of dolomite ($CaMg(C)_3$) and a slightly larger percentage of calcite ($CaCO_3$) than the other two regions (Table 23).

TABLE 23. MINERAL COMPOSITION OF BULK SAMPLES, AVERAGE PERCENTAGE (RANGE IN PARENTHESIS)

	Calcite	Dolomite
Montana	41	1
	(0-0.8)	(0-3)
Texas	1	13
	(0-3)	(7-20)
North Carolina	0	3
	0	(1-4)

Examination of bulk samples of talc from each region for free silica demonstrated the same trend as other contaminants (Table 24). Montana talc had <0.8 percent, which was the limit of detection. North Carolina had a slightly higher percentage, while Texas had the highest observed silica content.

TABLE 24. FREE SILICA BULK SAMPLES

Montana	<0.8% (Limit of Detection)
Texas	2.23%
North Carolina	1.45%

Respirable dust samples revealed the silica content in Montana and North Carolina to be generally below the limit of detection. The Texas talc had slightly higher levels of respirable silica.

Analysis for the presence of fibrous minerals was two-fold. The first analysis was with light microscopy utilizing phase contrast techniques. Light microscopy was used as a screening tool to detect the presence of fibers. Further analysis of samples from each region was performed utilizing analytical transmission electron microscopy (Table 25). Fibrous minerals were not detected in any samples of Montana talc.

TABLE 25. FIBROUS MINERALS

Montana

None Detected

Texas

Tremolite

Antigorite

North Carolina

Acicular Particles

There were two fibrous minerals identified in the Texas talc: tremolite and antigorite.

Antigorite, a serpentine mineral, was the major constituent. The fibers of both minerals ranged from 0.5 to 3.0 μm in diameter and 4 to 30 μm in length.

The morphology of the North Carolina talc was identified as acicular. The acicular particles had aspect ratios ranging from 5 to 1 to 100 to 1 with some diameters <0.1 μm. The acicular particles may have resulted from mechanical destruction of plates.

Other data concerning the composition of the talc from these facilities is being investigated and will be reported elsewhere.

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ROUNDTABLE DISCUSSION ON TALC

QUESTION (Dr. Cooper): How does one measure pleural thickening?

ANSWER (Dr. Langer): Pleural thickening is estimated by visual inspection of a chest x-ray. Using a specific classification for abnormal findings, one gauges the thickness and extent of the pleural lesion. The details may be explained by Dr. Lewinson who is here. Hilton do you want to add to this?

REMARK (Dr. Lewinson): The explanation is fine.

QUESTION (Mr. Ashton): I am from Johnson and Johnson. I ask for those of us who are not medically oriented; exactly what is pleural thickening?

ANSWER (Dr. Langer): Pleural thickening has been described as an abnormal increase in the thickness of the pleura (the linings of the chest wall and the lung) brought about by the development of scar tissue. This is the result of exposure to fibrous dust. It is mainly confined to inorganic mineral fiber insult although it has now been observed in fibrous glass workers as well. It means a fiber has penetrated the alveolar space, migrated to and lodged in the pleural tissue, and has initiated some scar response.

Dr. Gamble has suggested that pleural plaques, hyalinized thickened pleura, might be a prognostic indicator of mesothelioma since it is the same damaged tissue substrate from which the mesothelioma originates. This was suggested in some work of John Edge. He observed that within a select population of shipyard workers in Great Britain, men with pleural plaques developed mesothelioma more frequently than men without plaques. But the caveat raised in criticism to this hypothesis stated that men who had pleural plaques tended to be the oldest workers. The oldest workers also translated into men with greatest latency period since onset of exposure. Increased occurrence of mesothelioma would be expected in this group of asbestos-exposed workers. Those workers who do not develop asbestosis and die, those who do not develop lung cancers and die, are those who are candidates for mesothelioma. This is part of competitive risk. Edge's most recent paper (in the recent New York Academy of Science Asbestos Conference Meeting) indicates that the "plaque population" was "select" and the occurrence of pleural plaque may not be a prognosticator of more severe diseases to come.

REMARK (Dr. Lewinson): I think the question of whether pleural thickening or pleural plaques are a prognostic sign and whether they indicate that these people are of greater risk of developing mesothelioma is one which has not been resolved.

I think, however, to add to what you have said, you should bear in mind that anthophyllite experience in Finland: pleural plaques are extremely prevalent there, yet mesotheliomas have not occurred.

REMARK (Dr. Langer): That is absolutely correct. Mesothelioma has not been reported amongst the Finnish anthophyllite workers. Yet, pleural plaques are observed.

QUESTION (Mr. Clifton): I am from the U.S. Bureau of Mines. I notice that all of the exposure levels shown here tonight were given in mass units. This is quite confusing. We used mass units previously and then we had to go to fiber number. Now we are going back to mass units. How much of what were these people exposed to?

REMARK (Dr. Langer): I am going to leave that to our industrial hygienist. I think the question refers to the nature of the phases in a talc environmental sample. Total particulate mass says little.

ANSWER (Ms. Griefe): All of the data we collected were in milligrams. We did no impinger sampling. In New York, let me stand to be corrected, they did both cyclone sampling (which would give you milligrams per cubic meter) as well as the impinger sampling (which would give you million particles per cubic feet).

QUESTION (Mr. Clifton): You have not answered my question. I asked how much of what. How much fiber, how much talc?--What are the actual mineral phases and their form? You just gave us "milligrams". I do not know what "milligrams" represent, fibers, or otherwise.

ANSWER (Ms. Griefe): The respirable samples measured the total respirable dust in the air. There was no definition of the particulates on the filters whether, for example, half were fibers or half of it was talc. The cyclone samples, you are quite correct, measure what is in the air. The other airborne samples, for example, measure how many fibers, if there were fibers present.

QUESTION (Mr. Clifton): All you are saying then is that all you measured was "dust" in the air?

ANSWER (Ms. Griefe): On the cyclone samples, the personal samples; correct.

REMARK (Mr. Clifton): Well, the "dust" in the air does not tell us anything about the actual exposure.

QUESTION (Chairman Rowe): Mr. Clifton, what would you expect to find in a grinding mill that was grinding talc except talc dust?

ANSWER (Mr. Clifton): What I am saying is that if I am going to be regulated under the asbestos regulations I would expect field inspectors to count asbestos fibers, not talc fibers.

REMARK (Chairman Rowe): Ms. Griefe has already told you that there were not any fibers in it.

ANSWER (Ms. Griefe): Mr. Clifton, if I may clarify perhaps for those who do not understand. The figures that we gave for the dust concentrations were personal respirable breathing zone samples which were cyclone values which gives mass. We counted fibers on airborne samples if fibers were present. If fibers were not present, of course, we did not count them.

REMARK (Mr. Clifton): You did not indicate this in your presentation.

REMARK (Ms. Griefe): That is true.

QUESTION (Dr. Langer): Dr. Gamble, you have been asked if the talc dust were to be a fibrous dust how might this influence some of the data that were presented this evening?

ANSWER (Dr. Gamble): Well, I guess the closest data that I have would be the New York talc. In the comparison that we did, we saw no difference in the symptoms of cough; the prevalence of phlegm was higher in the New York talc; there was no difference in shortness of breath or in bilateral pleural thickening.

QUESTION (Mr. Schmitt): I am from the Flintkote Company. I would like to ask several questions which are not specific to the talc subject that we just discussed. They are related to some of the other studies which were mentioned this afternoon and which I suspect we will hear more of tomorrow. All of these relate to fibrous materials which I prefer not to call substitutes because they have been around as long, or if not, longer than asbestos. So, let us eliminate the word substitute. We are dealing with fibrous materials which may or may not become more prevalent in the workplace.

My questions relate to these medical exposure studies, relating exposure to human health effects. I get the impression that quite a number of these "other materials" are not quite as harmful as asbestos fiber. The questions that I have in my mind are: How do the smaller exposures affect the present studies? What effect does the shorter latency period have on these studies? If we were to compare these studies to the early asbestos studies, and I will pick 1954 as a particular year when there was considerable doubt about the harmful effects of asbestos fiber, are we in a "too early to tell" period? We are hearing the same kind of dispute going on among the medical fraternity on whether or not these exposures are harmful or not and to what degree they may or may not be harmful and we even get involved in high level statistical discussions and theory. If we were to repeat these studies 20 years from now what sort of verdict would we receive on some of these "other fibrous materials?". I will pose the question to you, Doctor Langer, and I will let you put it wherever you want it.

ANSWER (Dr. Langer): These are the underlying great questions. That is: That which we use as a substitute today, how safe is it really? What kind of data do we have? How long have we been studying the material? Is it long enough for observing clinical effects? And so on. You are right. It may take another period of 25 or 35 years before we find out that the substitute that was used today, put into some product with a hope of reducing health risk, has actually created a whole new "Pandora's box" of problems. Obviously this is the key to all the issues and discussions.

You may think that in 1954 we did not know very much about asbestos; yet if you read the literature you can go back further in time and discover that investigators were talking about asbestos and cancers many years before 1954. There were many signs that indicated that asbestos had great biological potential. Can we extrapolate these past experiences with the present? Perhaps.

For example, there exists a range of materials we call talc. Talc may represent a wide range of substances because as used in the industrial setting may include impure talc materials, or may be very pure talc. It could be the New York State talc or it could be the Montana talc. These are two extremes. For the New York State talc, there are data which indicate that inhalation produces significant disease. We have no similar data for Montana. Workers who work in New York State talc deposits develop talcosis, (bilateral interstitial lung scarring); they develop pleural plaques; they develop what appear to be asbestos bodies in their lung tissues; they develop lung cancers in excess of the anticipated amounts in the smoking-matched populations; they develop mesothelioma. Here the evidence is in. What about platy talc? Should you wish to wait another 30 years? Perhaps the materials that we are dealing with in the pure form are less biologically active. These produce lung scarring in laboratory animals. There are reports that pure talc produces talcosis in humans. Yet no data exists indicating excess cancers. Do these data sets mean that the active agents are the fiber contaminants and not the talc itself? Should we consider platy talc as a fibrogenic agent only and fibrous talc as both a fibrogenic and a carcinogenic agent? Limited data suggest this. The human studies by the Morgantown group involve small numbers of people. It is a very young population. These are people who just got into the study. If major clinical findings were found I would be aghast. With these groups we must have more time to observe them and determine if health effects are produced. I think we are going to have to wait a long time before we find out. The bottom line is this: some limited human data, some animal studies, some in vitro testing may point the way to a dangerous substance without waiting for the last case of pneumoconiosis to occur in a followed human population.

QUESTION (Mr. Mill): I am from Cabot Corporation. I would like to ask a question that may be germane to what you just said. Throughout this meeting we have heard a great deal about the geometry of the particles that cause health problems. We have heard very little or actually nothing about the surface chemistry. We know that certain related materials may stabilize free radicals on their surface. We know that material such as chrysotile can have a great amount of elemental substitution and therefore the surface chemistry can change a great deal. Has anyone made measurements of the surface chemistry of fibers and related them to some of the measured biological activity? Or have people merely tried to take the geometry and relate it to health effects?

ANSWER (Dr. Langer): I agree with you that surface is critical. Geometry is one of the factors which relates to aerosol stability; to inhalation potential; to penetration of particles to the alveolar space; to migration to the pleural surface. It is the geometric factor which controls how much dust gets into the lung and to which target tissues. It may also control ability of alveolar macrophages to ingest fibrous dusts (primarily length). But once it is in the lung, once it is at the target tissue, other factors come into play. These I believe, as you do, are the surface properties. When you talk about the stabilization of free radicals, we have noted that the grinding of chrysotile, which alters its surface, reduces the ability of the mineral to reduce diphenylpicryl hydrazyl to the hydrazine phase at its surface. Its membrane activity characteristics change also as do many other properties. When we talk about fibers we are talking only about inhalation potential; but when we talk about surface properties, we are talking about mechamisms. Lets back up for a minute. Lets talk about morphology and its relation to other important physical properties. Thin fiber means more fiber per unit mass of substance. Fiber number, reflects surface area. Surface area reflects bond number available on the surface. Some people think the electron migration on mineral surfaces, and their ability to interact with various compounds, is important. So do I. There has been much work from the Germans in this area. We have some work in our laboratory as well. Proton migration, hydroxyl release, trace metals, oxygen-silanol bifunctionality, geometric considerations, stereospecificity of surfaces for biological molecular moieties, etc., are but a few surface interactions possible.

We have been able to take a simple mineral like quartz and demonstrate its complex surface character. For example, we have taken quartz, size-fractionated quartz specimens, with different trace metal populations, measured the zeta potential (more or less a surface charge measurement) and observed vastly different membrane activities. Some are very potently hemolytic and others not. It is well known in the European literature that workers exposed to silica from iron mines, and those that are exposed to free silica in the presence of aluminum, have less silicosis. As a matter of fact the Germans had aluminum inhalation therapy for workers exposed to silica dust.

What we are saying is that you can take a single mineral substance, with different trace metals, ground in different ways, and produce vastly different biological potentials. It is truly simplistic to think that a fiber, because it is a fiber, produces disease. Biological activity must be surface related.

QUESTION (Mr. Mill): If you take chrysotile and you have a certain activity can you take a ceramic fiber made by XYZ Corporation and get the same activity?

ANSWER (Dr. Langer): No, I would not expect that.

QUESTION (Mr. Mill): Not at all?

ANSWER (Dr. Langer): Even if that fiber were to have the same dimensionality. Let us say you were to make a ceramic aluminum silicate fiber to put into a cigar and you were to make it of the dimensionality of 350 angstroms. You would have the same number of fibers, the same mass delivered to the target, the same surface area, the same particle number, the same hits per unit cell. Will it elicit the same response? I do not believe it for an instant.

REMARK (Mr. Mill): So what you are really saying is that because of the surface chemistry measurements it is very likely that something like a ceramic fiber would not be active.

ANSWER (Dr. Langer): I did not say that. I said that they produce vastly different responses.

REMARK (Mr. Mill): This might be a way of shortening the 20 years required for human studies. Animal studies are very important.

REMARK (Dr. Langer): I agree. What you are talking about now are mechanisms too, not just effects. If you are going to consider asbestos substitutes you should not introduce this material to the workplace and then wait 25 or 35 years to find out whether or not it is going to kill someone. You might do some animal studies, or even some in vitro tests, to determine membrane activity, protease induction or whatever. I agree with you, activity is a function of the surface characteristics of the material and not just the fact that it gets in there. Different minerals have different activities.

REMARK (Dr. Flowers): A comment on the surface chemistry. There has been some recent work regarding the reduction of biological activity of asbestos through the modification of its surface. There were two patents issued to Dow Chemical in October of 1979 which involved the modification of the surface of asbestos by coating the fiber with various metal salts. These essentially block the magnesium oxide-hydroxide sites. These preparations have been shown to reduce hemolytic activity, membrane effects, release of enzymes and general cytotoxicity. Tomorrow I will be presenting my talk about chemical detoxification of asbestos. There has been some agreement voiced that the geometry determines the site of deposition and surface chemistry determines biological effects. At least that is the premise.

QUESTION (Mr. Slovik): I am with the U.S. Bureau of Mines. I noticed on several of the slides that the samples were divided between nonsmokers and ex-smokers, and smokers. What was the criteria to determine an ex-smoker versus a nonsmoker and did the data vary with the length of time away from the cigarettes?

ANSWER (Dr. Gamble): We did not look at the length of time away from cigarettes. It was just simply if they had never smoked, they were a nonsmoker; if they had stopped smoking but had once smoked, they were classified as an ex-smoker. We did not really look at how much they had smoked or how long. It is just a simple categorization of those three groups.

QUESTION (Dr. Reeves): I have to come back to the question I asked earlier. Maybe I ought to address this to Doctor Langer. Did you know that the ACGIH (American Conference of Governmental Industrial Hygienists) lists "fibrous talc" with the same TLV value as crocidolite or anthophyllite? Under presently available evidence is this justified or is it not?

QUESTION (Dr. Langer): It has the same TLV as crocidolite?

ANSWER (Dr. Reeves): Yes.

ANSWER (Dr. Langer): I have often said that crocidolite is a more active fiber for producing mesotheliomas than most other mineral fibers. I believe this to be so on the basis of its geometry, the amount of fiber dose delivered to target cells. Crocidolite breaks down into extraordinarily small fibers. Crocidolite produces great numbers of mesotheliomas. Let us use that as a positive index. The question then is: should fibrous talc, true talc fiber, have the same TLV? I think this is a bit overextrapolated. They have very different biological activities, and different biological effects.

QUESTION (Dr. Reeves): Should it even have the same TLV as anthophyllite?

ANSWER (Dr. Langer): Let us take a different track. Suppose I were heading OSHA or MSHA, and it was my responsibility to protect workers. Suppose I had no data. Suppose the only data I had was morphology. If I read Pott's work, and the work in Europe which suggests that something which has a fibrous shape is active, a potent carcinogen, or Merle Stanton's work here in the United States which suggests the same, I would say "okay, let's have every fibrous mineral that is being mined come under the same TLV". If I had more data and information I would think that these should have different TLV's. But you know this is extraordinarily complicated. What if we were to do the following: what if every mineral fiber were to have its own TLV? What would we do in the case of the New York talc deposit? We would monitor for tremolite; we would monitor for anthophyllite; we would monitor for fibrous talc. We would have to distinguish among those phases. You cannot do this by phase contrast microscopy. We would have to count silica particles separately; the tirodite fibers, then hexagonite fibers; and so on. It is an extraordinarily difficult situation. Do we lower all of the TLV's or do we raise them all? Do we protect everyone, protect no one or only some?

REMARK (Dr. Ross): The TLV for asbestos fiber now being pushed is one-tenth of a fiber per cubic centimeter. You cannot operate a mill or a mine at that level.

REMARK (Dr. Langer): I will go one better. You cannot even regulate 0.1 fiber. You simply cannot count, without enormous time and expense at this level.

REMARK (Dr. Ross): Right. But that is the regulatory direction right now. Okay, now we just had the Department of Labor produce this document with 152 more fibrous minerals. We have got about half the earth's crust under the "asbestos" label. A regulation of a tenth of a fiber per cubic centimeter and the mining industry is dead as a doornail.

REMARK (Dr. Langer): I understand that problem and I agree with you that this is oversimplified, it is simplistic; it is injurious to the mining industry. I agree with that. It is based on the supposition, the assertion, that any fibrous particle which reaches the alveolar space migrates to the mesothelial surface and produces mesothelioma. Some believe that. I believe that there are profound differences in mineral species. But you have heard me say that before. What other alternatives exist? What are the data?

QUESTION (Dr. Reeves): Why then the same TLV?

ANSWER (Dr. Langer): In absence of data people extrapolate. There are no alternatives.

REMARK (Mr. Gill): The only thing that concerns me about the conversation between Drs. Reeves and Langer about fibrous talc and a TLV is that there is not any TLV for fibrous talc. There is not anything in ACGIH that says anything about fibrous talc. It says "asbestiform talc". That is a whale of a difference. I do not want to leave any of you with the impression that that is listed as a separate item, called "fibrous talc".

REMARK (Dr. Langer): I want to thank all of the participants at the roundtable discussion and especially the audience for the stimulating contributions.

OCCUPATIONAL EXPOSURES IN THE MANUFACTURE AND APPLICATION OF POLYURETHANE AND UREA FORMALDEHYDE INSULATION SYSTEMS

by

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ABSTRACT

Polyurethane and urea formaldehyde foams are used for residential side wall insulation and commercial insulation and roofing. Worker exposures to a variety of airborne contaminants were studied in the manufacturing and application of these two materials.

Industrial hygiene surveys at two polyurethane insulation manufacturing facilities and two application sites showed that airborne concentrations of methylene diphenyl diisocyanate (MDI), several amine catalysts, fluorotrichloromethane (Freon-11) and alpha-methyl styrene were very low during the manufacturing processes. Exposures of workers applying the polyurethane foam insulation were substantially higher, especially during insulation of the interior walls in a refrigerated warehouse. Airborne MDI levels during interior application exceeded the NIOSH recommended exposure limits.

Surveys at two manufacturing facilities of urea formaldehyde insulation showed airborne formaldehyde concentrations which approached the NIOSH recommended ceiling value (1 ppm) during resin production, and exceeded the recommended ceiling value during resin drum filling. Worker exposures to formaldehyde during foam installation from the exterior of residences (exterior retrofitting) ranged around 1 ppm, while formaldehyde exposures during open-bay insulation from the inside of residences exceeded 2 ppm. Observed levels of other airborne contaminants during urea formaldehyde foam manufacturing and application were very low.

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*Presented by Mr. Robert F. Herrick.

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INTRODUCTION

The rising cost of energy has resulted in increasing demand for thermal insulation materials, both in commercial and residential applications. Strong growth trends are predicted through 1983 for foam insulation materials used in residential side wall insulation and in commercial insulation and roofing. This study was undertaken to characterize worker exposures in the manufacturing and application processes of two foam insulation materials, polyurethane and urea formaldehyde foam.

The findings I will present today summarize in-depth surveys performed at two manufacturing facilities and two application sites for polyurethane foam; and two manufacturing facilities and two application sites for urea formaldehyde foam. This study was performed under NIOSH contract by Enviro Control, Incorporated of Rockville, Maryland, with the exception of one manufacturing facility which was surveyed by NIOSH personnel. Applicators were chosen so that for each foam insulation manufacturer selected, an applicator of the manufacturer's product was included in the study.

POLYURETHANE FOAM INSULATION

Manufacturing

Polyurethanes are thermoplastic polymers produced by the condensation reaction of polyisocyanate and hydroxyl-containing materials. In the case of polyurethane foams used for thermal insulation, methylene diphenyl diisocyanate, also known as diphenylmethane diisocyanate or MDI, or a mixture of about 50 percent MDI and 50 percent polymerized MDI, known as polymethylene polyphenyl isocyanate or PAPI reacts exothermally with one or more polyether polyols (compounds containing more than one hydroxyl group) in an aqueous reaction catalyzed by one or more organotin and amine catalysts. Carbon dioxide, which is a by-product of the polymerization, and volatile fluorocarbon blowing agents expand the polymer into a rigid foam.

The polyurethane foam insulation produced from this two component system is a rigid material with high resistance to the flow of heat. When expressed in terms of R values per inch of thickness, polyurethane foams typically have R values of approximately 6, as compared with about 4 for urea formaldehyde foam and 3 for mineral wool and fiberglass batts.

The polyurethane foam insulation systems included in this study are manufactured in facilities which specialize in compounding a wide variety of polyurethane systems. The base materials, consisting of MDI or PAPI, and polyether polyols are manufactured elsewhere and shipped by railcar or truck to the compounding facilities. The "A" side (or catalyst) of the polyurethane foam insulation systems is produced by repackaging liquid MDI or PAPI into 55 gallon drums from bulk storage, or by pumping MDI or PAPI to blend tanks where flame retardants (usually phosphate esters) are added and mixed at room temperature. The product is then transferred to 55 gallon drums. In the facilities studied, "A" side mixing and drumming is usually a one-man operation, performed two or three times a week. The "B" side component or resin is a mixture of ingredients which are also blended at room temperature. Some ingredients such as polyether polyols may be piped directly to the blend tanks from bulk storage, while other raw materials such as fluorotrichloromethane, amine catalysts, and alpha-methyl styrene are added by pouring or pumping from smaller containers. After blending for 30 to 60 minutes, the finished resin is pumped into 55 gallon drums. Quality control samples are collected during the blending process and samples of the finished resin are tested for foaming characteristics.

Personal and area samples were collected for MDl, several amine catalysts, fluorotrichloromethane, alpha-methyl styrene, and methylene chloride. Samples were analyzed by methods contained in the NIOSH Manual of Analytical Methods when appropriate methods were available. Sampling and analytical methods for the amines were developed by the contractor from NIOSH Method P&CAM 270 for aminoethanol compounds.

Discussion

At Plant A, personal samples collected during two periods of catalyst drum filling showed MDI concentrations ranging from less than the detectable limit to 2 ppb (Table 1). Exposure levels measured at Plant B during catalyst drum filling ranged from non-detectable to 5 ppb (Table 2).

Amine concentrations during resin blending and drumming at Plant A ranged from non-detectable to 170 ppb for dimethyl ethanolamine and non-detectable to 810 ppb for dimethyl cyclohexylamine (Table 3). At Plant B, tetramethylbutane diamine, triethylene diamine, and dimethyl ethanolamine were non-detectable, while concentrations of dimethyl cyclohexylamine ranged from non-detectable to 63 ppb (Table 4).

Concentrations of fluorotrichloromethane (Freon-11), which is added as a blowing agent, ranged from 0.95-96.0 ppm at Plant A and 4.4-193 ppm at Plant B (Table 5).

During equipment cleanup at Plant A, methylene chloride was measured at a level of 11 ppm over a 5-hour sampling period. Alpha-methyl styrene was not detected in personal air samples at either plant.

Application

Typical polyurethane foam insulation applications include roof exteriors, refrigerated warehouses, storage tanks, and other commercial applications. During this study, industrial hygiene surveys were performed during application of polyurethane foam to the roof of a church for the purposes of sealing and insulating and to the interior walls of a refrigerated room in a food warehouse.

Applicator A was surveyed at the church roofing site. The application process consisted of removing loose gravel and tearing off areas of defective roofing, then spraying polyurethane foam in four foot wide strips over the roof. The foam spraying was performed with an airless spray gun, with the A and B components heated to 60^0C and pumped to the spray gun, where mixing takes place. The foam expands to a thickness of approximately one inch and hardens within one minute. A silicone-based weather coating is applied after the foaming is completed.

Applicator B was surveyed during insulation of a refrigerated room within

TABLE 1. AIRBORNE MDI CONCENTRATIONS PERSONAL SAMPLES

LOCATION: PLANT A
ACTIVITY: DRUM LOADER, FILLING CATALYST DRUMS

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPB)	Range (PPB)
10/24/79	2	32	<2.0	<2.0
10/25/79	3	61	0.9	<1.0-2.0
				NIOSH Recommended Standard: 20 PPB Ceiling 5 PPB TWA

TABLE 2. AIRBORNE MDI CONCENTRATIONS PERSONAL SAMPLES

LOCATION: PLANT B
ACTIVITY: CHEMICAL OPERATION LOADING CATALYST DRUMS

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPB)	Range (PPB)
10/31/79	6	206	2.0	<0.8-5.0
10/31/79	3	99	0.6	<0.6-1.8
11/01/79	4	263	0.7	<0.2-2.3
11/01/79	2	177	0.3	<0.2-0.6
				NIOSH Recommended Standard: 20 PPB Ceiling 5 PPB TWA

TABLE 3. AIRBORNE AMINE CONCENTRATIONS PERSONAL SAMPLES

LOCATION: PLANT A
ACTIVITY: BLENDING AND DRUMMING RESIN

Compound	Number of Samples	Sampling Period TWA (PPB)	Range of Concentrations (PPB)
Dimethylethanol Amine	10	62.6	<64.0-170.0
Dimethylcyclohexyl Amine	10	240.2	7.0-810.0

TABLE 4. AIRBORNE AMINE CONCENTRATIONS PERSONAL SAMPLES

LOCATION: PLANT B
ACTIVITY: BLENDING AND DRUMMING RESIN

Compound	Number of Samples	Sampling Period TWA (PPB)	Range of Concentrations (PPB)
Tetramethylbutane Diamine	1		Not Detected (<56)
Triethylene Diamine	2		Not Detected (<15)
Dimethylethanol Amine	3		Not Detected (<15)
Dimethylcyclohexyl Amine	5	19.0	5-63.0

TABLE 5. AIRBORNE FLUOROTRICHLOROMETHANE CONCENTRATIONS

ACTIVITY: BLENDING AND DRUMMING RESIN

Location	Number of Samples	Sampling Period TWA (PPM)	Range of Concentration (PPM)
PLANT A	7	34.6	0.95-96.0
PLANT B	5	45.3	4.4-193.0

ACGIH - TLV: 1000 PPM

a food storage warehouse. The application process consisted of spraying foam onto the interior walls of the room to a thickness of approximately three inches. Application was performed by a two man team, using airless spray equipment similar to that used at Site A.

Personal samples were collected on the foam applicators and the helpers at Sites A and B during foam application and cleanup. Sample collection and analysis were performed as previously described in the surveys of the polyurethane manufacturing facilities.

Discussion

Table 6 presents the results of two days sampling during application of polyurethane foam to a church roof. The applicator's exposure to MDI ranged from non-detectable to 9 ppb, while the helper's exposures ranged from non-detectable to 1.9 ppb. Application of polyurethane foam to the interior walls of a refrigerated warehouse generated MDI exposure levels of non-detectable to 68 ppb with 8 hour time-weighted averages (TWA) as high as 13 ppb for the applicator, and exposures up to 28 ppb with a TWA of 6 ppb for the helper (Tables 7 & 8).

Airborne amine concentrations at Site A, the roof application, ranged from non-detectable to 480 ppb for dimethyl cyclohexylamine and non-detectable to 70 ppb for triethylene diamine (Table 9). Amine concentrations at Site B ranged from 17-170 ppb dimethyl cyclohexylamine and dimethyl ethanolamine was not detected (Table 10).

Concentrations of fluorotrichloromethane ranged from 1.6-13.0 ppm for the outdoor application at Site A and from 33-180 ppm for the interior application at Site B (Table 11).

Summary

At the two manufacturing facilities, airborne MDI concentrations during blending and drum filling were low, ranging from below the limit of detection to 5 ppb. Amine concentrations were below 1 ppm, fluorotrichloromethane levels ranged from 0.95-193 ppm, and alpha-methyl styrene was not detectable at a level of 84 ppb.

Airborne MDI levels measured during the outdoor application of foam to a roof ranged from below the limit of detection to 9 ppb for the applicator and the helper. The indoor application at Site B, however, generated MDI levels up to 68 ppb, with daily TWAs as high as 13 ppb. The data indicates that the indoor application of polyurethane foam presented higher exposures to MDI than the outdoor applications, however, differences in the chemical formulations of the systems may have had an effect on the observed MDI concentrations.

Concentrations of amine catalysts during foam application ranged from below limits of detection to 480 ppb. Fluorotrichloromethane exposures ranged from 1.6-180 ppm, and alpha-methyl styrene was measured at levels of 0.17 ppm and 0.21 ppm during interior foam application.

TABLE 6. AIRBORNE MDI CONCENTRATIONS
PERSONAL SAMPLES

LOCATION: SITE A, CHURCH ROOF
ACTIVITY: EXTERIOR APPLICATION OR POLYURETHANE FOAM INSULATION

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPB)	Range (PPB)
11/19/79	6 (Applicator)	255	2.7	<1.0-9.0
11/19/79	4 (Helper)	270	0.8	<1.0-1.5
11/20/79	10 (Applicator)	219	2.1	<1.3-5.3
11/20/79	7 (Helper)	214	1.3	<1.1-1.9
				NIOSH Recommended Standard: 20 PPB Ceiling 5 PPB TWA

TABLE 7. AIRBORNE MDI CONCENTRATIONS
PERSONAL SAMPLES

LOCATION: SITE B, REFRIGERATED WAREHOUSE
ACTIVITY: INTERIOR APPLICATION OF POLYURETHANE FOAM INSULATION

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPB)	Daily TWA (PPB)	Range (PPB)
12/19/79	7 (Applicator)	201	41	13	20-68
12/20/79	4 (Applicator)	96	27	5.0	<12-55
12/21/79	5 (Applicator)	134	17	5.7	<8.1-43
					NIOSH Recommended Standard: 20 PPB Ceiling 5 PPB TWA

TABLE 8. AIRBORNE MDI CONCENTRATIONS
PERSONAL SAMPLES

LOCATION: SITE B, REFRIGERATED WAREHOUSE
ACTIVITY: INTERIOR APPLICATION OF POLYURETHANE FOAM INSULATION

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPB)	Daily TWA (PPB)	Range (PPB)
12/19/79	7 (Helper)	236	13	6.0	4.7-28
12/20/79	3 (Helper)	159	2.2	0.6	1.8-4.8
12/21/79	3 (Helper)	114	7.0	2.0	5.6-9.2
					NIOSH Recommended Standard: 20 PPB Ceiling 5 PPB TWA

TABLE 9. AIRBORNE AMINE CONCENTRATIONS PERSONAL SAMPLES

LOCATION: SITE A, CHURCH ROOF
ACTIVITY: EXTERIOR APPLICATION OF POLYURETHANE FOAM INSULATION

Compound	Number of Samples	Sampling Period TWA (PPB)	Range of Concentrations (PPB)
Dimethylcyclohexylamine	6	189	<8-480
Triethylene Diamine	6	48	<30-70

TABLE 10. AIRBORNE AMINE CONCENTRATIONS PERSONAL SAMPLES

LOCATION: SITE B, REFRIGERATED WAREHOUSE
ACTIVITY: INTERIOR APPLICATION OF POLYURETHANE FOAM INSULATION

Compound	Number of Samples	Sampling Period TWA (PPB)	Range of Concentration (PPB)
Dimethylethanolamine	4		Not Detected (<8)
Dimethylcyclohexylamine	4	55	17-170

TABLE 11. AIRBORNE FLUOROTRICHLOROMETHANE CONCENTRATIONS PERSONAL SAMPLES

ACTIVITY: POLYURETHANE FOAM INSULATION SPRAYING

Location	Number of Samples	Average Concentration (PPM)	Range of Concentration (PPM)
SITE A	4	5.7	1.6-13.0
SITE B	4	99.0	33-180

ACGIH TLV: 1000 PPM

UREA FORMALDEHYDE FOAM INSULATION

Manufacturing

Urea formaldehyde foam insulation systems consist of two components: a resin and a catalyst or foaming agent. The resin component is produced by condensation reactions of urea and formaldehyde under alkaline conditions forming methylol derivatives which undergo further polymerization to form the resin. The particular characteristics of each resin are determined in part by the presence of additives such as alcohols and phenol. The catalyst of foaming agent is an aqueous mixture of acids and sulfonic acid emulsifiers.

The manufacturing facilities included in this study specialize in the production of urea formaldehyde insulation systems. Both facilities produce resin in a batch process, manufacturing 2-10 batches per week. The production schedule varies with seasonal demand for insulation materials. At Plant C, the resin component is manufactured in batches, utilizing 37 percent formaldehyde solution, prilled urea, furfuryl alcohol, ammonium hydroxide, a sugar solution, and a proprietary flame retardant as ingredients. The resin is formed by partial polymerization of these base materials in an alkaline reaction mixture. The finished resin is cooled and packaged in 55 gallon drums.

At Plant D, the resin component is manufactured by a patented process utilizing methylolurea as the base material, along with phenol and small amounts of acetaldehyde. The resin is produced by polymerization of methylolurea, phenol, and urea in an acid catalyzed reaction. The reaction proceeds until the desired degree of condensation is acheived, then the reaction is stopped, a fructose solution and additional urea are added, and the mixture is cooled and packaged in 55 gallon drums.

The foaming agent or catalyst is a mixture of sulfonic acid emulsifying agents and dilute acids. At Plant C, the foaming agent is produced as a concentrate which is diluted with water by the foam applicator. Plant D produces a foaming agent which is delivered to the applicator at working strength.

Personal and area samples were collected for formaldehyde, ammonia, and furfuryl alcohol during the resin manufacturing processes at Plant C. At Plant D, samples were collected for formaldehyde, acetaldehyde and phenol. Samples were analyzed by methods contained in the NIOSH Manual of Analytical Methods. Formaldehyde measurements at Plant D were also made by collection on solid sorbent tubes and analysis by ion chromatography as described in a method developed by the NIOSH Division of Physical Sciences and Engineering.

Discussion

Formaldehyde levels measured in samples collected during resin production at Plant C ranged from 0.12 to 0.55 ppm (Table 12). Higher levels were observed during resin drumming, with personal samples collected on the cook's assistant ranging from 1.8-5.4 ppm (Tables 13 & 14).

Plant C packages its resin in returnable drums, and these drums are washed with a hot water spray before they are reused. Small amounts of resin may be

TABLE 12. AIRBORNE FORMALDEHYDE CONCENTRATIONS
PERSONAL SAMPLES

LOCATION: PLANT C
ACTIVITY: FORMULATING RESIN - COOK

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPM)	Range (PPM)
9/25/79	4	518	0.27	0.20-0.35
9/26/79	5	506	0.36	0.12-0.55
				NIOSH Recommended Standard: 1 PPM (Ceiling)

TABLE 13. AIRBORNE FORMALDEHYDE CONCENTRATIONS PERSONAL SAMPLES

LOCATION: PLANT C
ACTIVITY: FORMULATING AND DRUMMING RESIN (COOK'S ASSISTANT)

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPM)	Range (PPM)
9/25/79	3	506	0.47	0.17-1.8
9/26/79	6	460	0.78	0.29-5.4
				NIOSH Recommended Standard: 1 PPM (Ceiling)

TABLE 14. AIRBORNE FORMALDEHYDE CONCENTRATIONS
PERSONAL SAMPLES

COOK'S ASSISTANT - DRUM FILLING

Date	Sampling Period	Activity	Concentration
9/25/79	62	Drum Filling - Lid Off	1.8
9/26/79	30	Drum Filling - Lid Off	5.4
	25	Drum Filling - Lid On	2.1
	30	Drum Filling - Lid Off	2.6

NIOSH Recommended Standard: 1 PPM (Ceiling) in the drum as it returns to the plant. Formaldehyde levels measured during drum washing ranged from 0.2-0.74 ppm (Table 15).

Although the foaming agent does not contain formaldehyde, levels of 0.06-0.34 ppm formaldehyde were observed in personal samples of the foaming agent blender (Table 15). This employee spent brief periods of time near the reactor.

Ammonia concentrations ranged from non-detectable to 15 ppm for the cook and cook's assistant during resin production (Table 16). Furfuryl alcohol was non-detectable at a level of 0.3 ppm.

At Plant D, formaldehyde levels ranged from 0.34 - 0.45 ppm during resin production. Personal samples collected during resin drumming ranged from 0.18 - 1.28 ppm. Phenol was non-detectable at a level 0.3 ppm, and acetaldehyde was non-detectable at a level of 1.3 ppm.

Application

In the application of urea formaldehyde foam, the catalyst-foaming agent mixture is pumped into an application gun where it is expanded into bubbles with compressed air or nitrogen. The foamed catalyst is mixed with resin at the nozzle of the application gun. The resin and catalyst react on the surface of the bubbles and the resin cures to self-supporting foam within one minute. Complete curing of the foam may require 48-72 hours up to several weeks after application, depending on factors such as outside temperature and formulation of the foam. The urea formaldehyde foam produced from this system is a solid material with a density of approximately 2.5 lb/cubic foot.

Urea formaldehyde foam insulation is installed in the sidewalls of existing structures; this application is known as retrofit. It is also used in sidewall insulation in new construction by a procedure known as open-bay application. Both application techniques were surveyed in this study.

Applicator C was surveyed during retrofit of three residences. The application team consisted of five men, one of whom was a manufacturer-certified applicator. The retrofit application began with all five men opening the structure. Opening is the industry term for gaining access to the wall cavities, and in approximately 90 percent of the jobs it is done from outside the house. Holes are drilled in masonry and wood. Aluminum siding and shingles are usually removed, and the weatherboard is knocked through with a hammer. Before foaming begins, the applicator performs several quality control procedures, including measurements of foam density, and test cones known as beehives are shot to evaluate foam properties. Improper proportions of the components can cause a condition known as vanishing foam, in which foam appears to be normal when it leaves the gun but collapses within about 10 minutes. Applicators sometimes taste the foam as part of their quality control procedures. When the resin, catalyst, and compressed air or nitrogen are metered in the correct proportions, the foam has the consistency of shaving cream. Unlike polyurethane foam, urea formaldehyde foam is fully expanded when it leaves the gun. In retrofit applications, it flows into cavities and sets within about one minute.

TABLE 15. AIRBORNE FORMALDEHYDE CONCENTRATIONS
PERSONAL SAMPLES

LOCATION: PLANT C
ACTIVITY: DRUM WASHING AND FOAMING AGENT BLENDING

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPM)	Range (PPM)
DRUM WASHING				
9/25/79	2	407	0.52	0.23-0.74
9/26/79	3	411	0.30	0.20-0.47
FOAMING AGENT BLENDING				
9/25/79	2	411	0.24	0.15-0.34
9/26/79	3	396	0.18	0.06-0.26
				NIOSH Recommended Standard: 1 PPM (Ceiling)

TABLE 16. AIRBORNE AMMONIA CONCENTRATIONS
PERSONAL SAMPLES

LOCATION: PLANT C
ACTIVITY: FORMULATING RESIN

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPM)	Range (PPM)
9/27/79 (Cook)	4	477	1.9	0.96 - 15
9/27/79 (Cook's Assistant)	4	507	0.28	<0.13 - 1.6
				NIOSH Recommended Standard: 50 PPM (Ceiling)

The applicator begins foaming and as he moves along a wall, other members of the crew follow behind and remove excess foam and close the house, returning it to its original condition.

Applicator C also performed open-bay application to buildings under construction. In open-bay applications, the air pressure is increased and a thin coat of foam is sprayed onto the wall surface. After this scratch coat has been applied, the air pressure is reduced and the cavity between the studs is filled with foam. In some cases, a plastic trowel is attached to the end of the application hose to smooth the foam. Approximately 15 minutes after foaming, a flat shovel is used to scrape away the excess foam so the insulation is flush with the studs. A polyethylene sheet is nailed to the studs to form a vapor barrier.

Applicator D was surveyed during retrofit of two residences. The application process was virtually identical to that described for Applicator C, except that Applicator D used a two man team to install the foam.

Personal and area samples were collected during setup, foam application, closing, cleanup, and maintenance activities associated with foam installation. Sampling and analysis were performed as previously described in the surveys of the insulation manufacturing facilities.

Discussion

For Applicator C, personal exposures to formaldehyde during exterior retrofit ranged from non-detectable to 1.2 ppm (Table 17). The formaldehyde exposures of laborers ranged from non-detectable to 0.65 ppm, with the highest exposures observed during cleanup of waste foam around the site (Table 18).

Area samples collected in the van during site preparation, foaming cleanup, and driving back to the warehouse ranged from 0.07-2.0 ppm. Concentrations of formaldehyde in the warehouse before and after the work day ranged from 0.17-0.85 ppm. Samples collected for ammonia and furfuryl alcohol were below detectable limits of 0.1 and 0.3 ppm, respectively.

Applicator C was also sampled during open-bay foam installation. Formaldehyde levels during foaming ranged from 1.1-2.4 ppm, and from 0.86-2.3 ppm during foam scraping (Table 19).

Applicator D was sampled during exterior retrofit foam installation. Formaldehyde exposures to the applicator ranged from 0.06-1.3 ppm, while the applicator's assistant was exposed to formaldehyde at levels ranging from non-detectable to 0.5 ppm (Tables 20 and 21). The highest exposures were measured while the assistant was working closely with the applicator (Table 21). Area samples collected in the van during site preparation, foaming, cleanup, and driving back to the warehouse ranged from 0.02 to 0.33 ppm.

Summary

In the survey of the urea formaldehyde insulation manufacturing facilities, the highest formaldehyde levels were observed during resin drum filling with levels as high as 5.4 ppm measured. Formaldehyde levels during resin production ranged from 0.12 to 0.74 ppm. The only other contaminant which was detectable

TABLE 17. AIRBORNE FORMALDEHYDE CONCENTRATIONS PERSONAL SAMPLES

LOCATION: APPLICATOR C
ACTIVITY: APPLICATOR EXPOSURES DURING EXTERIOR RETROFIT

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPM)	Range (PPM)
12/06/79	4	261	0.37	<0.03 - 1.2
12/10/79	5	249	0.22	0.03 - 0.83
12/11/79	3	145	0.27	0.14 - 0.35

TABLE 18. AIRBORNE FORMALDEHYDE CONCENTRATIONS PERSONAL SAMPLES

LOCATION: APPLICATOR C
ACTIVITY: LABORER EXPOSURES DURING EXTERIOR RETROFIT

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPM)	Range (PPM)
12/06/79	2	172	0.08	0.06 - 0.11
12/10/79	5	312	0.18	<0.04 - 0.65
12/11/79	3	90	0.20	0.15 - 0.32

TABLE 19. FORMALDEHYDE EXPOSURES DURING OPEN-BAY APPLICATION - 12/12/79

Sampling Period (Min)	Concentration (PPM)	Activity
34	1.1	Foam Application
31	2.4	Foam Application
30	1.1	Foam Application
27	1.6	Foam Application
34	0.86	Foam Scraping
35	2.3	Foam Scraping
31	1.6	Foam Scraping
12	2.3	Foam Scraping

TABLE 20. AIRBORNE FORMALDEHYDE CONCENTRATIONS PERSONAL EXPOSURES

LOCATION: APPLICATOR D
ACTIVITY: APPLICATOR EXPOSURES DURING EXTERIOR RETROFIT

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPM)	Range (PPM)
11/27/79	5	234	0.12	0.07 - 0.52
11/28/79	5	291	0.34	0.10 - 0.80
11/29/79	1	32	0.45	
11/30/79	6	299	0.71	0.06 - 1.3

TABLE 21. AIRBORNE FORMALDEHYDE CONCENTRATIONS
PERSONAL EXPOSURES

LOCATION: APPLICATOR D
ACTIVITY: ASSISTANT'S EXPOSURE DURING EXTERIOR RETROFIT

Date	Number of Samples	Total Sampling Time (Minutes)	Sampling Period TWA (PPM)	Range (PPM)
11/27/79	2	99	0.19	0.06 - 0.37
11/28/79	3	162	0.14	<0.09 - 0.26
11/29/79	2	186	0.07	<0.03 - 0.13
11/30/79	5	351	0.06	<0.04 - 0.50

during resin production was ammonia, which was measured in concentrations up to 15 ppm.

Formaldehyde exposures to applicators performing exterior retrofit ranged from non-detectable to 1.3 ppm. Open-bay application was found to produce significantly higher formaldehyde levels, ranging from 0.86-2.4 ppm. Other air contaminants were not detected during retrofit or open-bay applications.

Conclusions

In-depth industrial hygiene surveys of two polyurethane foam insulation manufacturers showed that worker exposures to MDI, a variety of amines, flourotrichloromethane, and alpha-methyl styrene were very low. Surveys of polyurethane insulation application sites showed airborne MDI levels above the NIOSH recommended standard during interior foam application, while exposures during outdoor foam applications were substantially lower. While the lack of natural ventilation during interior application was certainly a contributing factor to the higher observed MDI concentrations, differences in the chemical formulations of the foam systems may have also had an effect.

Surveys at urea formaldehyde foam manufacturers showed that airborne formaldehyde levels during resin production approached the NIOSH recommended ceiling value and exceeded it during resin drum filling. Concentrations of other air contaminants were generally very low.

Application of urea formaldehyde foam by exterior retrofit resulted in worker exposures at about the recommended ceiling value, while interior (or open-bay) application generated formaldehyde levels substantially in excess of the recommended ceiling values. Comparisons of exposures during exterior retrofit and open-bay application of the same foam system indicate that lack of ventilation during indoor application is the cause of elevated airborne formaldehyde concentrations.

Of the eight manufacturing and application facilities studied, only the manufacturers of polyurethane systems had implemented engineering controls to reduce exposure levels. The applicators of polyurethane insulation sometimes wore paint spray respirators, however, due to the sensitizing properties of MDI, these respirators do not provide an adequate degree of protection. The manufacturers and installers of urea formaldehyde foam were not employing engineering controls or respiratory protection. Preliminary results of inhalation studies indicate that formaldehyde has caused nasal cavity cancer in rats. NIOSH has recommended that exhaust ventilation be incorporated in urea formaldehyde manufacturing processes, especially drum filling. Workers applying urea formaldehyde insulation should wear chemical cartridge respirators with full-face masks.

DISCUSSION ON FOAMS

QUESTION (Mr. Wright): I am with the Steelworkers. I have a couple of quick technical questions. One is about the sampling for MDI; was MDI sampled for as a vapor or as a particulate or as both?

ANSWER (Mr. Herrick): We used the base method, which is recognized to undersample particulate MDI; therefore, I believe our values may be on the low side in the application processes. In the manufacturing processes, I think the values are fairly accurate because there was no aerosolization of the MDI. I think there is a strong possibility that we undersampled in the application sites.

REMARK (Mr. Wright): There is at least one recent study in a manufacturing location that indicated a sizeable fraction of MDI in the air existed as a particulate.

REMARK (Mr. Herrick): I think you are referring to the studies performed at Tulane where MDI was vaporized. In that case, a sizeable fraction of MDI would certainly exist as particulate, but we were dealing with MDI at room temperature. The MDI was not heated to generate a known concentration, which is what was done in the other studies.

Your point is certainly well taken, however; NIOSH is actively engaged in developing better methods for sampling isocyanides in their particular forms.

QUESTION (Mr. Wright): A question about that same reference. Was there any "Moca"* used as a catalyst in the system, or in other foaming systems, or for making an insulation material?

ANSWER (Mr. Herrick): We investigated that in the course of the surveys and found to the best of our knowledge that "Moca" is not being used throughout the industry in insulation systems at this time.

QUESTION (Chairman Rowe): How long has this material been used in the United States and what percentage of the market does it take up in comparison to the conventional types of insulation?

QUESTION (Mr. Herrick): Which system are you referring to?

ANSWER (Chairman Rowe): Both the polyurethane and the urea-formaldehyde foam versus, say, fiberglass.

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*Trademark for 4,4-methylenebis(2-chloro-aniline).

ANSWER (Mr. Herrick): The market share for ureaformaldehyde was doing quite well over the last 2 or 3 years, but as you all know, there has been adverse publicity given to those products on the market, which could cause problems. So the market share for ureaformaldehyde has pretty much dropped right off the bottom. When we did these surveys, we found there were really only two companies engaged in what could even be considered close to full-time production of ureaformaldehyde foam systems.

In the case of polyurethane, it is quite a different picture. The future is very bright for polyurethane systems. There are a couple of companies expanding their capability to produce MDI and one of the major reasons is the anticipated use in insulation systems.

I am sorry I do not have any hard numbers for market share, but I could get them for you. This information will be published as a NIOSH technical report and will have more of the background information you refer to.

HUMAN PULMONARY FUNCTION STUDY (5 YEARS) ON OCCUPATIONAL ISOCYANATE EXPOSURE

by

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ABSTRACT

A previously unexposed industrial cohort in TDI (toluene diisocyanate) manufacturing was investigated over a 5-year period with collection of environmental and biologic response data. In addition to scientific questions addressing the incidence, determinants and mechanism of susceptibility to low levels of TDI vapor (between 4 and 5 percent of the population became TDI "reactors"), attention was directed toward the possibility that a general adverse effect on airways function might occur in this population of 223 men. Extensive personal monitoring characterizing the exposures of 42 jobs through 2000 continuous 8-hour personal samples allowed the individual reconstruction of cumulative exposure in each study participant. Measurement of lung function included lung volumes, maximum expiratory flow rates and diffusing capacity. Lung function testing was performed at the plant site on nine different occasions over the 5-year period, using the mobile pulmonary function laboratory.

Smoking adversely influenced the longitudinal decline of ventilatory function (FVC and FEV_1). After accounting for smoking and atopic status, significant differences between exposure categories were found for annual declines in FEV_1 FEV percent, and FEF_{25-75}. The exposure-related effect on annual declines in these measurements of expiratory flow was slight in the total population, but when the study group was divided by smoking history it was found that the exposure-related effect was confined to the nonsmokers and masked or not present in the smokers. Additionally, some TDI reactors have failed to attain preexposure or presensitization values of FEV_1 or FEF_{25-75} despite transfers to other areas in the chemical complex.

I am going to present a brief summary of a study that was recently reported to NIOSH in final form. This report will be available to the public.

In 1973 with the support of the National Institute of Occupational Safety and Health, and with the cooperation of a major chemical company, the members of my unit were invited to engage in a five year prospective

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longitudinal study of a working population exposed to TDI, toluene diisocyanate. This population works in a process which occurs before the foaming process that was discussed in the previous presentation. TDI manufacturing had not previously been a part of the manufacturing operations of this chemical plant in southwest Louisiana. We had a unique opportunity to study a population before their exposure.

The purpose of this very complex study, a multi-disciplinary study, was to determine the influencing factors in any acute or chronic respiratory effects that may emerge from this exposure.

There were initially 168 members of this working population in the TDI plant. In the first two years of this study, new members of the work force engaged in this aspect of the manufacturing were added to the cohort. Ultimately, 277 people were available for study. These individuals were studied at various times over a 5-year period, not at each of the observation points, but with a minimum number being required for inclusion in the data analysis.

The TDI plant that we studied cost about $60 million to build in the early to mid-1970's. At that time gaskets were not too expensive, but TDI spills caused by bad gasketing occurred. When a large leak occurs there is, of course, a very high vapor concentration of this volatile material.

One of the known effects of exposure to isocyanates, either in manufacturing or in foaming operations, is an acute respiratory disease, properly called "asthma." TDI produces intolerance, at times, to low levels of exposure. In our population between 4 and 5 percent of the population became intolerant. Age and smoking status varied among the individual workers, but smoking did not seem to be an important influencing factor in producing intolerance. Some workers had positive TDI bronchial provocation challenges in the lab, whereas some did not, at the levels of exposure that we used. Some were atopic, that is they had an allergic diathesis, as was indicated by two or more positive skin tests to common inhalant allergens whereas others were not. Those eliciting a positive response were about what you would expect in the general population; therefore, atropy was not an important influencing or predicting factor.

Some individuals had known exposures to high concentrations of TDI; some individuals developed symptoms as early as less than a week after the first exposure, whereas others took as long as a couple of years to first develop these symptoms. Most of these individuals did have complaints in the first year.

We were able to reproduce the bronchial spasm in the laboratory with varying patterns, as have other researchers. By carefully monitoring the levels of exposure and following the medical course using workers' respiratory status and various patterns of bronchial provocation, a pattern emerged. An acute response, where a drop in ventilatory capacity occurs immediately after a 15-minute exposure, or a late response, where a drop may occur some hours later and is usually less readily reversed, or a dual response of both an acute and a late response may develop.

TDI is a simple chemical and if it acts as an allergen, it presumably acts as a haptene that must be conjugated with a protein. By using what was touted to be, perhaps, an advanced rash test (developed at the University of Pittsburgh) that measured specific Ig antibodies, we found that only 15 or 18 percent of our acute reactors did in fact, have positive tests. We could not demonstrate that IgE allergy, the classical asthma type allergy, was the important factor in the mechanism of most of these instances.

Something did seem to happen in these people at the cellular level. The ordinary release of cyclic AMP by mast cells, which is good for the bronchi, dilates the bronchi. When stimulated with known activators of cyclic AMP, the response is limited. There seems to be an alteration of the dose response curve for the cyclic nucleotide. For some reason, people who have become reactive have a depressed release or ability to release cyclic AMP. We do not know exactly why 4 to 5 percent of an exposed population become intolerant.

What about the outcome of these acute problems? A followup of these acute reactors, shows two measurements of expiratory flow, even after sensitization was recognized. After the workers were ostensibly removed from unexposure, approximately 40 percent of these reactives continued to have unanticipated declines in their ventilatory function. This suggested to us that some long-term effects may occur even after exposure ceases.

This has also recently been found with western red cedar dust exposure and other causes of occupational asthma. Investigators in Vancouver found that removing these individuals from exposure did not always lead to complete reversal of their disease.

We were interested in characterizing exposure to TDI, to learn its more general effect on respiratory health and the development of dose response relationships. Initially, we measured exposure with a continuous monitor using a chemically impregnated paper tape. In the first 2 years, there were frequent excursions above 0.02 parts per million in both production areas and in drumming.

In the last three years, we were able to develop personal sampling information. We would produce 8-hour continuous profiles of the workers' isocyanate vapor exposure. There was considerable variability and fluctuation in the exposure over an 8-hour shift. We performed 1,949 characterizations of the personal exposures of persons representing 42 job titles, to reconstruct for each individual a personal cumulative exposure to use to correlate with the biological events that we saw. If you take 1,949, 8-hour time-weighted samples, and perform a frequency distribution in various concentrations (parts per billion), you see a marked skewing. The distribution becomes more symmetrical if you convert this to a large scale. We were then able to develop high, moderate, and low exposure categories. Ultimately, we were able to generate exposure categories for each of these 42 jobs. Then, by finding out who worked where and when, each individual was, by summation, assigned an exposure profile. In a healthy population the percent predicted for measurement of expiratory flow, lung volumes, and diffusing capacity is nearly 100 percent. The average annual change of forced expiratory volume in one second, a very stable measurement, will be used to illustrate changes in the population studies. As an indicator of long-term air-ways effect we used the annual change in lung function, by exposure groups. Using this method we found the smoking effect which would be expected and an exposure effect. We found a significant effect on average annual change in lung function by TDI exposure in people who never smoke; a difference in average annual change of somewhat less than 40 milliliters per year. The high exposure group had about the same decline per year as the smokers. In the ex-smokers and the current smokers the trend was in the same direction, but there was some masking of this exposure-related effect, which was significant in the people who never smoked.

This is not the first time an occupational exposure effect has been demonstrated only in non-smokers. It is commonly held that smoking enhances an exposure effect. But it does not necessarily have to do that, especially when we are dealing with air-ways disease and not malignancy. The effect here, fairly stated, is a small effect. The average annual decline in FEV_1 and other expiratory flows, showed about the same results based on cross-sectional predicted data. It is only about 27 or 30 milliliters per year, and the high exposure group did not exceed that level very much. In longitudinal studies, however, that decline may be smaller but even so, it is a small effect. It is a modest effect and we think it is related to exposure, after such things as smoking and atrophy are accounted for in the regression equations.

In conclusion we have demonstrated that there are substantial exposures in this manufacturing operation. Both continuous area and personal monitors have demonstrated that essentially everybody in this study had at one time or another been exposed. Over the 5-year period, there was no systematic exposure trend demonstrated. We found that these various expiratory flow rates, which are measurements or indicators of air flow function or obstruction, are significantly related after controlling for smoking and atopic status to TDI dose. The same significance was established whether or not we measured dose by cumulative method or time spent above a certain level. As I have already mentioned, these expiratory flows were not significantly different from the annual declines from cross-sectional studies. But these particular expiratory flows were significantly greater than those prediction values would lead you to expect. There was a smoking effect, which helped to validate these longitudinal data. And, as I have already mentioned, the effect of TDI exposure of FEV_1 annual change or other expiratory flows appears mainly in the nonsmokers and was perhaps masked in smokers.

Prevalence of bronchitis and shortness of breath increased from the pre-exposure baseline in the high exposure category, as measured by cumulative exposure, but these increases were not significant. As I have mentioned, about 4 percent of the population became acutely reactive or sensitized or susceptible or intolerant, which is in keeping with the limited data that are available on this in the world literature. You have to remember that in this situation, for the first time it was possible to get true incidence data, that is the appearance of sensitization. In the other limited studies that are available that was not possible because preexposure information was not available. Smoking and atrophy did not seem to be important predictors of whether or not somebody would become intolerant. As I have already suggested, some of these people have, so far, failed to obtain preexposure or presensitization expiratory flows. This is in keeping with the very latest reports a month or two ago at the American Thoracic meeting, from the Vancouver group on the western red cedar dust situation.

Although we did not feel justified in going above 0.02 parts per million in the bronchial provocation studies in the laboratory, we know that where this has been done, some people who are clinically intolerant to TDI vapor will respond not to 0.02 parts per million but to higher levels of exposure. Therefore, a negative challenge test at 0.02 parts per million does not necessarily mean the individual has not become reactive or intolerant. It just means that he is not reacting to that level. Again, there are ethical and perhaps even legal questions involved in exceeding the standard or TLV in the laboratory in exposure situations.

These last conclusions deal primarily with the immunology, which I have already indicated, the bottom line suggests that we still do not know. We think something is going on at the receptor level. Why some people have this abnormality and develop an inadequate response to stimuli to secrete cyclic AMP is not clear.

DISCUSSION ON ISOCYANATE

QUESTION (Mr. Anderson): I am wondering if it is possible that there might be isocyanates in cigarette smoke that allow one to build up an immunity to isocyanates, like one can build up an immunity to arsenic by being exposed to low levels of arsenic?

ANSWER: (Dr. Weill): That is an interesting question. We came up with several possible explanations and that was not one of them.

Cigarette smoke is very complex; as all of you know, it contains many chemicals and particulates, Isocyanates do occur widely. For instance, of some interest to us was one of our individuals who became TDI reactive all of a sudden and could not tolerate one of his favorite foods, radishes. He developed severe bronchial spasm when he ate radishes. He ultimately lost his TDI sensitivity and then could eat radishes again. Radishes do contain an isocyanate. I do not know about cigarette smoke, but it is an interesting possibility.

QUESTION (Mr. Sales): All along we have been talking about rather stable minerals with long lifetimes, but isocyanates are noted for their reactivity. I wonder if the fact that these materials are active has been taken into account.

ANSWER (Dr. Weill): You are quite right. When TDI hits the moist bronchi mucosa, it does change; it is no longer in its chemical form and it is highly reactive. Something about either it or its transformation or its product produces the kinds of problems that I summarized.

We do have an interest in this. It is a very hard thing to get at. It would easily be studied in the animal model; unfortunately, so far there is no animal model for TDI asthma.

CRITERIA FOR ANIMAL, TISSUE CULTURE, AND BIOCHEMICAL STUDIES ON ASBESTOS, MINERAL DUSTS, AND PROPOSED SUBSTITUTES FOR ASBESTOS

by

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ABSTRACT

There are numerous studies available on the animal toxicity and adverse tissue effects of asbestos and mineral dusts to allow development of short-term *in vivo* and *in vitro* tests of proposed substitutes for asbestos. The *in vitro* tests available comprise measures of viability, cytotoxicity, hemolytic activity, release of enzymes from damaged cells, and similar measures of cellular or biochemical functions. *In vivo* testing involves a wider variety of studies ranging from short-term immunologic, histologic, and physiologic response in animals to lifetime studies such as determination of tumor yields or chronic fibrosis. Appropriate testing of proposed substitutes requires use of tests to compare mechanisms of action for proposed substitutes with those for asbestos and other mineral dusts.

I have been attending the sessions over the past few days. I was particularly interested at the first session in the remarks by Dr. Warren Muir in regard to the duty of the EPA, under TSCA and various legislative acts, to eliminate the unreasonable risk of exposure to asbestos in the United States environment.

During the workshop we have had descriptions of some rather detailed inhalation toxicology studies going on with respect to vitreous glass. These studies have been in progress for about two and one-half or three years. With the protocols felt necessary for the *in vivo* tests described, there is something like a million dollars a year being spent over a five year period.

In the past few days some 60 substitutes have been presented here. If all of these were tested according to the protocols for vitreous glass, that would be roughly $300 million to perhaps half a billion dollars to test substitutes for asbestos. That amounts to $60 million a year for a five year period to test substitutes for a material that represents a raw material cost of about $220 million a year in the U.S. economy.

Obviously, one would not be able to do complete in vitro and in vivo tests for all proposed substitutes to that extent regarded by some as necessary to produce data for risk assessment and unreasonable risk decisions under TSCA procedures. One approach that comes out of this economic dilemma is to use in vitro tests to establish priorities for in vivo tests.

My particular talk actually addresses two different levels of criteria for the animal, tissue culture, and biochemical studies on asbestos, mineral dust, and proposed substitutes.

Sometimes these two different levels of criteria may be in conflict with each other. One level is that of the regulatory or administrative criteria for generation of data to determine exposure and adverse effects so that one can make unreasonable risk decisions and develop regulations. The other is the scientific level of criteria to do a fairly complete characterization of toxic effects and identification of underlying mechanisms for the action of asbestos or proposed substitutes. In developing a proposed substitute for asbestos and reaching the stage of commercial development, we came up against some very difficult questions, essentially in the realm of: Where do we go from here to develop data that will be persuasive to EPA? If successful in our tests, what data would allow the use of our material as a substitute for asbestos?

Figure 1 starts with the basic unreasonable risk decision process and the mandate under the toxic substances control act for EPA to manage the degree of risk on exposure to chemical, physical agents, and other substances to an acceptable level in our environment. In going through the unreasonable risk decision process I will show how this relates to developing acceptable test protocols and criteria for substitutes.

The unreasonable risk decision process or evaluation starts with the submission of notices and test data. In the pre-manufacturing notification process there is a requirement for a determination of whether the information submitted is sufficient to perform evaluations of risk.

If the data is sufficient, then the first requirement is to see if there is a substantial risk as indicated by the data using appropriate risk assessment methodologies. I understand that such methodologies are presently under development.

If the data in the pre-manufacturing notice is insufficient to allow an assessment of risk, then the EPA, under Section 4 of TSCA, can require the submission of additional data. This leads to another reiteration of the pre-manufacturing notification and highlights the issues of acceptable test criteria.

During this time, it is the duty of the administrator to provide interim protection, and he has various options for unreasonable risk protection during the decision process. He can limit or prohibit manufacture or use, seek an injunction through the court process, or decide to invoke one or all

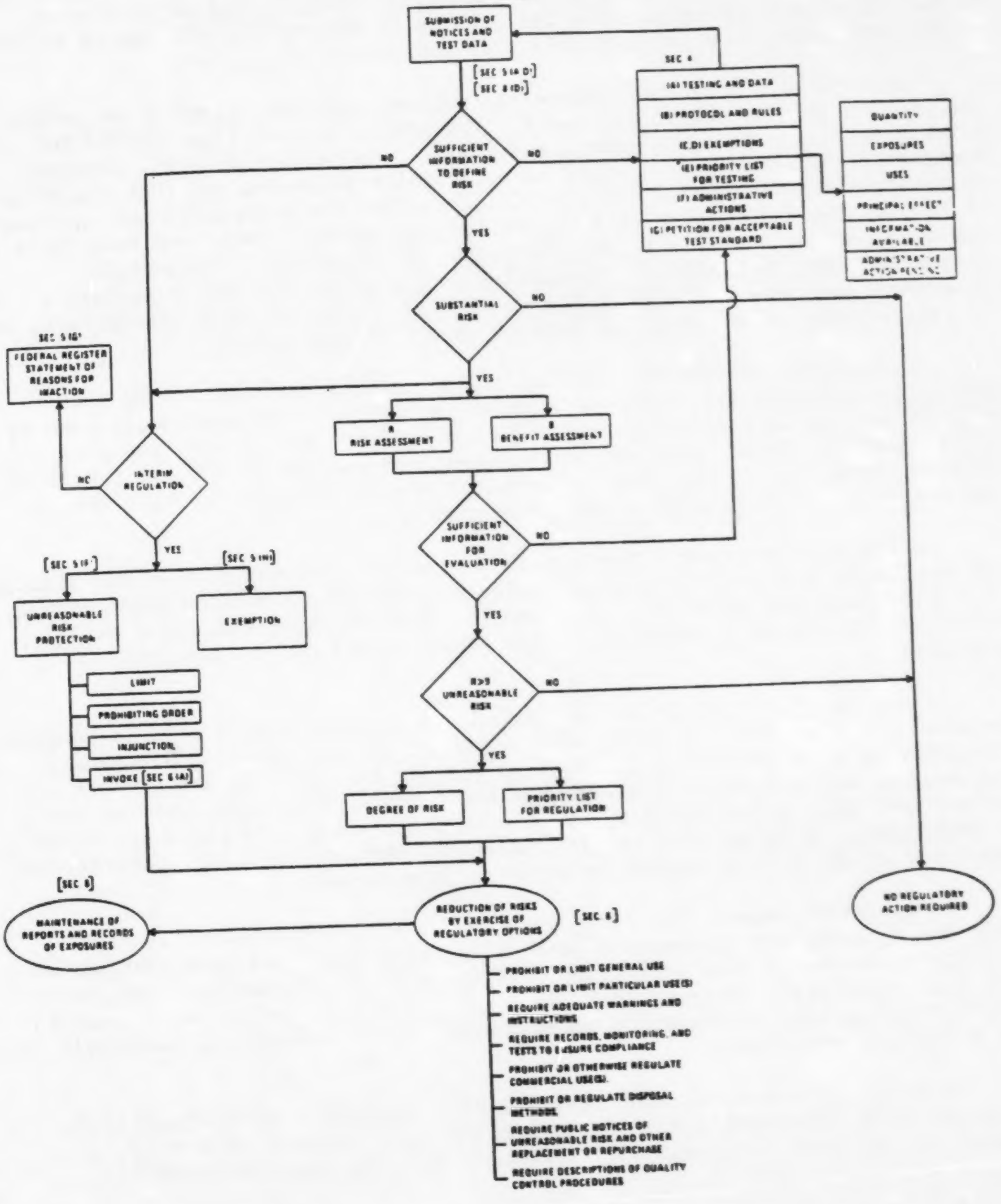
SUBMISSION OF NOTICES AND TEST DATA
[SEC 5(A)(D)]
[SEC 8(D)]
SUFFICIENT INFORMATION TO DEFINE RISK
NO
NO
YES
SEC 4
(A) TESTING AND DATA
(B) PROTOCOL AND RULES
(C,D) EXEMPTIONS
(E) PRIORITY LIST FOR TESTING
(F) ADMINISTRATIVE ACTIONS
(G) PETITION FOR ACCEPTABLE TEST STANDARD
QUANTITY
EXPOSURES
USES
PRINCIPAL EFFECT
INFORMATION AVAILABLE
ADMINISTRATIVE ACTION PENDING
SUBSTANTIAL RISK
NO
YES
SEC 5(G)
FEDERAL REGISTER STATEMENT OF REASONS FOR INACTION
A RISK ASSESSMENT
B BENEFIT ASSESSMENT
INTERIM REGULATION
NO
YES
[SEC 5(F)]
[SEC 5(H)]
UNREASONABLE RISK PROTECTION
EXEMPTION
LIMIT
PROHIBITING ORDER
INJUNCTION
INVOKE [SEC 6(A)]
SUFFICIENT INFORMATION FOR EVALUATION
NO
YES
R>B UNREASONABLE RISK
NO
YES
DEGREE OF RISK
PRIORITY LIST FOR REGULATION
[SEC 8]
MAINTENANCE OF REPORTS AND RECORDS OF EXPOSURES
REDUCTION OF RISKS BY EXERCISE OF REGULATORY OPTIONS
[SEC 6]
NO REGULATORY ACTION REQUIRED
PROHIBIT OR LIMIT GENERAL USE
PROHIBIT OR LIMIT PARTICULAR USE(S)
REQUIRE ADEQUATE WARNINGS AND INSTRUCTIONS
REQUIRE RECORDS, MONITORING, AND TESTS TO ENSURE COMPLIANCE
PROHIBIT OR OTHERWISE REGULATE COMMERCIAL USE(S).
PROHIBIT OR REGULATE DISPOSAL METHODS
REQUIRE PUBLIC NOTICES OF UNREASONABLE RISK AND OTHER REPLACEMENT OR REPURCHASE
REQUIRE DESCRIPTIONS OF QUALITY CONTROL PROCEDURES

Figure 1. Unreasonable risk decisions and required procedures under TSCA.

of the seven regulatory options contained under Section 6 of TSCA. These options range from labeling to an outright ban of material. The administrator may simply require that the manufacturer maintain records and conduct medical surveillance of employees during the marketing, testing, and interim manufacturing of such material while the process of determining the degree of risk or the existence of an unreasonable risk continued.

Under Section 4 of TSCA, there are various sections allowing the administrator to require additional tests. The public can petition the EPA for a variance during test marketing, under 4(b). Under Section 4(g), Congress recognized that these tests would be potentially expensive and that the public, or interested individuals, could petition the EPA for acceptable test protocols to develop the information in a cost-effective manner. Data from such tests could be used to submit a pre-manufacturing notification. A plausible assumption test protocols, if successful, would allow the EPA to perform a risk assessment and make a determination on whether or not to allow manufacture, use, or distribution of the proposed product in the United States.

The decision process for testing and successful introduction of the proposed substitute for asbestos is shown in Figure 2. To eventually come up with an acceptable substitute, one must use *in vitro* and *in vivo* tests that are available. These tests may be obtained from reviews of the literature of what has been done to test fibers and materials in the past. I will discuss the criteria for acceptable tests, subsequently.

Initially, the process starts with a material that has promise and retains the desirable attributes for a particular application or various applications as a substitute for asbestos. For example, this could be a chemical modification of the asbestos surface to allow asbestos to serve as its own substitute.

If the initial finding is that the material causes severe effects compared to asbestos, then such material, even though it is desirable, is assigned a low-priority as a substitute for further *in vivo* testing. If the effects are not severe, but the material shows moderate effects, then such material would be assigned as a medium priority substitute for testing. If there are slight, or negligible, effects, such material would be assigned as a high priority and desirable substitute to expend funds for *in vivo* tests.

In a similar manner for the *in vivo* tests, if there are severe effects, then the material may represent a substantial risk requiring more testing and interim unreasonable risk protection. If there is no substantial risk, under the TSCA procedures, there would be no need to propose regulations or conduct further evaluations to determine unreasonable risks. Therefore, that would be an acceptable substitute.

If there is a determination that the data suggests a substantial risk, then the TSCA unreasonable risk determination would apply as presented in Figure 1. If there is essentially a finding that the benefits derivable

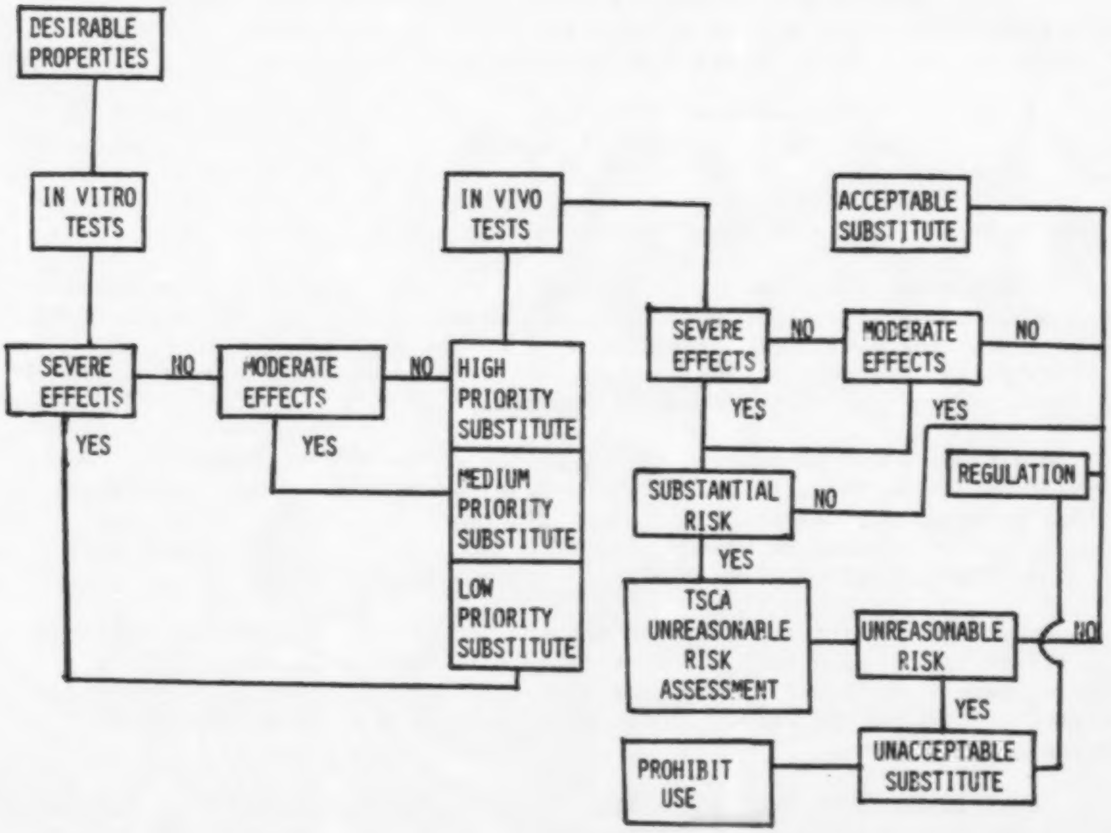
DESIRABLE PROPERTIES
IN VITRO TESTS
IN VIVO TESTS
ACCEPTABLE SUBSTITUTE
SEVERE EFFECTS
NO
MODERATE EFFECTS
NO
HIGH PRIORITY SUBSTITUTE
YES
YES
MEDIUM PRIORITY SUBSTITUTE
LOW PRIORITY SUBSTITUTE
SEVERE EFFECTS
NO
MODERATE EFFECTS
NO
YES
YES
SUBSTANTIAL RISK
NO
REGULATION
YES
TSCA UNREASONABLE RISK ASSESSMENT
UNREASONABLE RISK
NO
YES
PROHIBIT USE
UNACCEPTABLE SUBSTITUTE

Figure 2. Decision process for selecting materials to test.

from the use of the substance exceed the cost of allowing its use, then there is no unreasonable risk, under TSCA. Such a material would be an acceptable substitute.

When the benefits do not balance the costs associated with use of the material, that would be a finding of an unreasonable risk and, therefore, an unacceptable substitute. EPA may decide to prohibit its use, or to exercise appropriate regulatory options. The administrator may propose regulations that would allow a social management of the degree of risk to an acceptable level and, therefore, that would be an acceptable substitute under special regulatory conditions.

In a similar manner, if there are moderate effects, then there needs to be a determination of whether those moderate effects represent a substantial risk, based upon extent of exposure and adverse effects data.

If there is no substantial risk, then there is no need for regulation. Therefore, that would be an acceptable substitute. If there is a substantial risk, an unreasonable risk determination is required. The decision process as to whether to prohibit or to regulate applies, and the material is determined to be an acceptable substitute or an unacceptable substitute.

This process takes considerable time to obtain approval of a material with desirable properties. Persuading EPA to allow that material to be used as an acceptable substitute, involves some rather complex regulatory and administrative procedures. For new materials, the assessments depend upon in vitro and in vivo tests in animal systems.

One other point is that in regard to the EPA policy statement on the regulation of exposures to asbestos, the data used to establish its current policy is primarily epidemiologic data. In general, in vitro or in vivo studies are not quoted as direct support for EPA policy, but they are quoted as providing biological plausability to epidemiologic findings.

In developing information on a new product or a substitute for asbestos, the epidemiologic data will not be available for most substances. It is also extremely difficult, on the basis of in vitro tests and in vivo tests, to predict perhaps the epidemiologic experience of a human population in 20 years or 35 years.

This creates a dilemma for making unreasonable risk decisions. Instead of having the desirable kinds of information on exposure of humans from epidemiologic data, the characterization of the adverse effects in regulatory decision making will be necessarily based upon surrogate data. Such data include production data, proposed geographic distribution of the chemical substance or agent under review, and extrapolation from available in vitro and in vivo data to what the adverse effects might be in humans.

In trying to determine what kinds of tests one might conduct to be persuasive to the EPA in its exercise of its regulatory duties to manage or possibly eliminate, the unreasonable risk from exposure to asbestos or proposed substitutes, I reviewed various documents -- the National Academy of Science document on asbestos, the Criteria Document from NIOSH, the update of the Criteria Document, the various publications of Federal agencies and trade associations, discussing the biological properties and activities of asbestos. From this review, I prepared a list of the types of in vitro and in vivo studies that were quoted in support of any regulations, recommendations, and proposed policy. Very few in vitro studies were used in these documents. Also a limited number of in vivo studies were quoted in support of the recommendations in these various documents.

The next step was to review the available literature on the biological activity of asbestos. Some 180 articles were found. However, very few of these were quoted in the previous documents that I reviewed. These articles discussed the biological effects, including the molecular biology and cellular interactions of asbestos in biological systems. Various in vitro studies that would be available to serve as tests to evaluate potential substitutes are listed in Table 1.

Hemolytic activity is a test used to demonstrate the irritation of cell membranes using red blood cells. The adverse effect of asbestos and other materials on cell membranes has been commented upon several times during the workshop. Asbestos and some proposed substitutes irritate membranes and either cause release of substances from these membranes, in this case, hemoglobin which serves as its own indicator or actually destroys the integrity of the cell.

Hemolytic activity or high hemolytic activity of a proposed substitute would suggest that it is equally active in this particular effect when compared to asbestos.

There are various cytotoxicity studies concentrating upon macrophages, fibroblasts, tracheal epithelium slices, and bronchial epithelium slices.

The significance of the macrophage studies is that cytotoxicity in these cells represents interference with the second line of defense of the body, and in this case, the lungs. The immobilization of the macrophages or disturbance of the biochemistry of the macrophage, would suggest an interference with the defense mechanism.

The fibroblast is an important cell in the alveolar wall, and fibroblasts are responsible for synthesis of elastic tissues. There is a need for a certain amount of elastic tissues to maintain the structural integrity of the lungs, particularly the alveoli.

The tracheal epithelium is a critical target tissue, as is the bronchial epithelium. These types of cytotoxicity studies are selected on that basis. Use of critical tissues could provide the basis for design of acceptable test protocols for evaluation of exposures to asbestos or proposed substitutes.

DNA synthesis is another measure which can be a rather sophisticated indication of new cell growth. In addition, depending upon the repair rates,

TABLE I

IN VITRO STUDIES

TEST	SIGINIFICANCE
HEMOLYTIC ACTIVITY	IRRITATION OF CELL MEMBRANES OR LYSIS OF RED BLOOD CELLS
CYTOTOXICITY	
MACROPHAGES	INTERFERENCE WITH DEFENSE MECHANISMS
FIBROBLASTS	IMPORTANT CELL IN THE ALVEOLI WALL
TRACHEAL EPITHELIUM	CRITICAL TARGET TISSUE
BRONCHIAL EPITHELIUM	CRITICAL TARGET TISSUE
DNA SYNTHESIS	INDICATES DEGREE OF NEW CELL GROWTH
ENZYMATIC ACTIVITIES	INDICATES POTENTIAL IRRITANT EFFECTS ON MEMBRANES OR SUBCELLULAR STRUCTURES
MUTAGENIC ACTIVITY	INDICATES INTERFERENCE WITH THE FLOW OR EXPRESSION OF GENETIC INFORMATION
MITOTIC RATE	INDICATES THE DEGREE OF NEW CELL GROWTH AND DIVISION
HISTOCHEMICAL	ALLOWS COMPARISONS OF CONTROL CELLS WITH EXPOSED CELLS

new DNA synthesis could indicate the rate of repair that is going on as a result of damage.

Enzymatic activities -- There are numerous studies where LDH and transaminases have been measured in a supernatant indicating that the substance under test is an irritant on membranes or subcellular structures.

Mutagenic activities, such as dominant lethal assays, looking at reversal of mutations on rather exotic kinds of cells, such as Salmonella mutants, indicate a potential for interference with the flow or expression of genetic information. This might be a useful test to propose as part of an acceptable test protocol.

Mitotic studies indicate the degree of new cell growth and division. There are various chemical studies which allow comparisons of control cells with cells exposed to a proposed substitute. Based upon the performance of the material in rapid screening tests, such tests could be used to establish a priority for conduct of more extensive _in vivo_ tests.

In Table II, the _in vivo_ studies that have been previously reported are inhalation studies, histochemical studies and tumor yield studies. Inhalation studies can be classified into short-term exposure tests and long-term exposures. The short-term exposure tests are usually at high doses and short durations of exposure. Short-term high dose studies are used to estimate responses in a short period of time and levels immediately hazardous to life. Extrapolations beyond the duration of the experiment can be questionable.

Long term exposures are primarily for the lifetime of the animal and attempt to develop dose response data which allow an improved prediction of chronic effects.

These kinds of studies, however, because of the long term exposures, number of animals involved, and the number of doses, are fairly expensive (as indicated by the studies described for vitreous glass).

Histochemical studies can be characterized into four basic types, described in the literature. These are carcinogenesis, production of fibrosis, the release of enzymes which indicates the irritant effects on tissue and membranes, and the clearance of particles or interference with the clearance of particles which indicates possible interference with macrophage mobility and/or interference with phagocytosis of inert particles.

Non-specific immune response studies indicate another level of interaction with macrophage cells through having the proposed substitute stimulate the release of a macrophage factor, thus indicating a generalized immune response.

Tumor yield studies are perhaps the most significant in terms of evaluating proposed substitutes. With high positive results, one would have the greatest degree of unreasonable risk. In these studies, there are often positive controls where a known carcinogen is given, along with the proposed

TABLE II

IN VIVO STUDIES

INHALATION AND LUNG STUDIES	
Short Term Exposures	Acute reponses possible in short time
Long Term Exposures	Development of dose response data and improved prediction of chronic effects
HISTOCHEMICAL STUDIES	
Collagen Synthesis	Indicates potential to produce fibrosis
Release of Enzymes	Indicates possible irritant effects on tissues and membranes
Clearance of Particles	Indicates possible interference with macrophage mobility and/or phagocytosis
Immune Response	Indicates possible stimulation of macrophage factor to induce immune response
TUMOR YIELD STUDIES	
Positive Controls	Indicates validity of test system
Negative Controls	Establishes baseline for comparisions
Particle Exposure Only	Indicates potential for direct carcinogenisis
Particle Exposure with Known Carcinogen	Indicates potential to promote carcinogenisis

substitute. This approach indicates the validity of the test system. If the agent under test is capable of producing cancer, the system would detect that there is an increase in tumor yield, or that there are cancers.

There is also a need for use of inert fibers in studies to establish a baseline for ratios of tumor yields to compare with the effects of various proposed substitutes. Other protocols that have been used are particle exposure only and particle exposure with a known carcinogen. These protocols are intended to look at either direct carcinogenesis by the substance or look at the potential to promote carcinogenesis.

This brief perusal of the available literature has led to six criteria in Table III for biological tests for evaluation of proposed asbestos substitutes. The first criteria is that the experimental protocol must include both positive and negative control for comparisons of toxic effects.

Secondly, a range of doses should be used which are sufficient to define dose response. There has been some discussion during the workshop that there is a threshold below which the body can defend itself against asbestos and other fibrous materials. However, the current risk assessment approach, particularly for carcinogenic substances is that the dose response is a linear or non-threshold relationship.

The statistical design of the test must be adequate to analyze all identified sources of variation, and to estimate confidence intervals. A fourth extremely important criteria for the testing system is that the chemical purity and physical characteristics of the material under test must be determined. This is extremely important in dealing with a complex material such as asbestos because a material characterized as chrysotile, for example can come from a variety of sources in the world. Chrysotiles from various sources have different chemical compositions and different physical characteristics in terms of particle size, fiber diameter, and fiber lengths. A chrysotile from Cassiar, for example, does not appear to be as active in certain kinds of tests as a chrysotile from a South African mine or a chrysotile from the eastern portion of Canada.

The biological variables must be clearly defined as specified. This includes variables such as the animal species and diet. All essential factors must be specified so that one can reproduce the test and make comparisons between tests performed at different laboratories or using different materials.

Finally, the tests should include provisions for independent verification of results by other investigators, this could be by use of an independent test system, or the use of more than one species to verify that this is a general biological response rather than a species' specific type of response.

We are interested in developing a set of acceptable test protocols so that in two or three years we can submit appropriate data to the Environmental Protection Agency to register what we think is a viable substitute for asbestos. The biological data, if positive in indicating a lack of biological activity

TABLE III

CRITERIA FOR BIOLOGICAL TESTING OF PROPOSED ASBESTOS SUBSTITUTES

1. THE EXPERIMENTAL PROTOCOL MUST INCLUDE BOTH POSITIVE AND NEGATIVE CONTROLS FOR COMPARISONS OF TOXIC EFFECTS.
2. A RANGE OF DOSES SUFFICIENT TO DEFINE DOSE-RESPONSE IS RECOMMENDED.
3. STATISTICAL DESIGN OF THE TESTS MUST BE ADEQUATE TO ANALYZE IDENTIFIED SOURCES OF VARIATION AND TO ESTIMATE CONFIDENCE INTERVALS.
4. THE CHEMICAL PURITY AND PHYSICAL CHARACTERISTICS OF THE MATERIAL UNDER TEST MUST BE DETERMINED.
5. BIOLOGICAL VARIABLES MUST BE CLEARLY DEFINED AND SPECIFIED.
6. TESTS SHOULD INCLUDE PROVISIONS FOR INDEPENDENT VARIFICATION OF RESULTS BY OTHER INVESTIGATORS, USE OF A SIMILAR TEST SYSTEM, OR USE OF OTHER SPECIES.

or an acceptable level of biological risk must be persuasive to the regulatory decision makers in the EPA. This approach would allow our proposed substitute or others to be distributed, used, and manufactured in the United States.

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